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DESCRIPTION AND RELATIONSHIPS OF THE LONGBILL SPEARFISH, *TETRAPTURUS BELONE*, BASED ON WESTERN NORTH ATLANTIC SPECIMENS¹

C. RICHARD ROBINS

The Marine Laboratory, University of Miami

AND

DONALD P. DE SYLVA

Department of Biological Sciences, University of Delaware

ABSTRACT

Tetrapturus belone Rafinesque is described on the basis of specimens from the Western North Atlantic. A synonymy is given and the relationships discussed. The species is compared with other Atlantic billfishes and with *T. angustirostris* of the Indo-Pacific. *T. angustirostris* is recorded for the first time from off the Chilean coast. The genus *Tetrapturus* is re-defined, its synonymy given and the constituent species of Istiophoridae realigned according to a proposed phylogeny. A key is given to the species of Istiophoridae exclusive of the sailfishes, *Istiophorus*.

INTRODUCTION AND ACKNOWLEDGMENTS

The fishes of the family Istiophoridae, despite their interest to sport and commercial fishermen, and the large size obtained by many of them, have been little understood until recently. Many workers have contributed substantially to the knowledge of their systematics, biology and distribution in the last ten years. Among them may be mentioned Hubbs and Wisner (1953), Voss (1954), LaMonte (1955), Rivas (1956a, b), Smith (1956), de Sylva (1957, 1958), Gehringer (1957), Royce (1958), LaMonte *et al.* (1958—a collection of five papers by LaMonte, Krumholz and de Sylva, variously authored), and Morrow (1957a, b; 1959a, b). Japanese workers, to whom the istiophorids are commercially important, have made important contributions: Hirasaka and Nakamura (1947), Nakamura (1949),

¹Contribution No. 287 from The Marine Laboratory, University of Miami, and Contribution No. 15 from the University of Delaware Marine Laboratories.

Nakamura *et al.* (1953), Ueyanagi (1954, 1957a, b), Kamimura and Honma (1958), Honma and Kamimura (1958), and Ueyanagi and Yabe (1959).

Most of these studies concern marlins variously placed in *Makaira*, *Istiompax*, *Kajikia* and other less frequently accepted genera. Few discuss the spearfishes, *Tetrapturus sensu stricto*. Fish enthusiasts, as Al Pflueger of Miami, have known and recognized the spearfish among sportfishing catches in the Florida region for many years. In the past four years the writers have examined fourteen spearfish from the tropical western Atlantic. Data on three additional specimens were provided by Victor G. Springer, Robert H. Gibbs, Jr., and Donald S. Erdman. Other records have been determined from photographs.

Tetrapturus belone Rafinesque was described from a specimen caught at Sicily in the Mediterranean. Little exact information is available on Mediterranean fishes in general and later workers have not distinguished *T. belone* from other istiophorids (Legendre, 1928; Lozano Cabo, 1958). Although some differences may exist between the Mediterranean and western Atlantic spearfishes we assign all records to *belone* rather than risk adding to the already large istiophorid synonymies. Such problems will be resolved only when specimens of *belone* from the Mediterranean become available.

Many have aided billfish research at The Marine Laboratory before and during this period. Unfortunately, space permits the mention of only a few. Al Pflueger, Miami taxidermist, has made available most specimens reported upon here, and has provided photographs of earlier catches and similarly has been a willing supplier of valued information. Joseph T. Reese, taxidermist at Fort Lauderdale, and his associates also provided specimens and information. Francesca R. LaMonte, James E. Morrow, Harvey R. Bullis, Jr., Gilbert L. Voss, Victor G. Springer and Robert H. Gibbs, Jr. supplied data for other records of *Tetrapturus* and information on other species. John K. Howard, through his many contacts, his extensive library on the Istiophoridae and his enthusiasm, has been a constant source of information. Finally, Walter R. Courtenay, Jr. took many photographs and aided in the preparation of the plates.

METHODS

For brevity, especially in the tables, the following abbreviations are used.

D₁ = spinous or first dorsal fin

D₂ = second dorsal fin

C = caudal fin

A₁ = first anal fin

A₂ = second anal fin

P₁ = pectoral fin

P₂ = pelvic fin

orig. = origin (in reference to fins)

c.p. = caudal peduncle

In describing morphometry, ichthyologists commonly translate data into thousandths or hundredths of standard length. Two deviations are employed here. The bill of istiophorids exhibits marked allometry. Excluding larval and other early stages, the bill is negatively allometric in *Istiophorus* and *Tetrapturus*, but positively allometric in *Makaira* (as defined below). Such allometry is sufficient to mask the true nature of other characters. For these reasons we follow Rivas (1956a) in using body length (tip of mandible to fork of tail) in place of standard length. Secondly, experience shows that error in measurement of these giant fishes renders more than two digits non-reproducible. Percentage values are therefore rounded to two places only.

The original field numbers (1-23) are maintained in the tables although they do not form a size sequence. So many observations are identified by these numbers that confusion of data would result by introducing new numbers at this time.

The diagnosis and description that follow are based only on western Atlantic specimens.

Tetrapturus Rafinesque

Tetrapturus Rafinesque, 1810: 54-55 (*T. belone*, type species by monotypy).
Skeponopodus Nardo, 1832: 99 (*nomen nudum*); 1833: 415-419 (*S. typus*,

[= *T. belone* Rafinesque], type species by virtue of the name *typus*).

Tetrapterurus Bonaparte, 1841: 19 (emended spelling).

Tetrapterus Agassiz, 1843: 7, 89-92, table E (emended spelling).

Tetraplurus Vérany, 1847: 492-494 (misprint for *Tetrapturus*?).

Scheponopodus Canestrini, 1872: 112 (emended spelling).

Tetraperus Radcliffe, 1926: 112 (misprint for *Tetrapturus*).

Marlina Grey, 1928: 47 (*Tetrapturus mitsukurii* Jordan and Snyder, [= *T. audax* Philippi], type species by monotypy; the use of *Marlina* at the generic level is probably a slip).

Kajikia Hirasaka and Nakamura, 1947: 13-14 (*Kajikia formosana*, [= *Tetrapturus audax* Philippi], type species by monotypy).

Pseudohistiophorus de Buen, 1950: 171 (*Tetrapturus illingworthi* Jordan and Evermann [= *T. angustirostris* Tanaka], type species by original designation).

Lamontella Smith, 1956: 32 (*Tetrapturus albida* [sic] Poey, type species by original designation and monotypy).

Tetrapturus belone Rafinesque

LONGBILL SPEARFISH

Figures 1-5, Tables 1-3

Tetrapturus belone Rafinesque, 1810: 54-55, fig. 1 (original description; type locality: Sicily). Cuvier, 1829: 201 (redescription, distribution). Valenciennes, 1831: 205, 280, pl. 227-228 (description of specimen from Messina). ?Sassi, 1846a: 391 (Ligurian Sea, *non* Rafinesque *sed lessonae* Canestrini, according to Canestrini, 1861a [= *T. albidus* Poey]). ?Sassi, 1846b: 111 (Ligurian Sea, *non* Rafinesque according to Canestrini, 1861a, and Tortonese and Trotti, 1949 *sed T. lessonae* Canestrini [= *T. albidus* Poey]). Costa, 1850: 10 (Taranto, 1937). Gulia: 1861: 12 (compiled). Barceló y Combis, 1868: 388 (Mallorca, rare). Gulia, 1871 (Malta). Canestrini, 1872: 12 (Taranto, rare; *Scheponopodus typus* Nardo a synonym). Lütken, 1876b: 1-21 (compared). Trois, 1880: 643-645 (description of vertebral column and comparison with *Xiphias*). Goode, 1883: 296, 306-307, 347 (*T. imperator* [Schneider] has priority over *T. belone* Rafinesque; synonymy, distribution, size, food habits). Goode, 1884: 337 (distribution). Cocco, 1884: 37 (Messina). Kolombatović, 1886 (Split). Carus, 1889-1893: 676 (description, distribution in Mediterranean, synonymy). Ninni, 1912: 271 (Venice). Jordan and Evermann, 1926: 30-31 (distribution [Mediterranean], description, measurements, counts, size, synonymy). de Buen, 1935: 101 (in part, compiled). Tortonese, 1940: 173-178 (comparisons). LaMonte and Marcy, 1941: 21-22, fig. (figured [Rafinesque's original drawing]; systematics and relations; considered to be possibly a young specimen of *Makaira*). Soljan, 1948: 376, 389 (Adriatic Sea; synonymy). Tortonese and Trotti, 1949: 134 (Ligurian Sea; discussion, synonymy, habitat, specimen deposited in Genoa Museum). Spartà, 1953: 58-62, pl. (eggs and larvae from Straits of Messina; adults are caught off Messina in August and September). *LaMonte, 1955: 325-326 (discussion; Florida included in distribution). Albuquerque, 1956: 855, fig. 360 (listed from Madeira; counts, description). Gehringer, 1957: 169 (in part, compiled; ?*Tetrapturus* postlarvae from Western Atlantic are probably *Makaira nigricans*). *Hoese, 1958: 341 (Texas, compiled). *Migdalski, 1958: 70 (Puerto Rico and Florida) lower figure opposite p. 100 except for fish on upper right).

Skeponopodus, Nardo, 1832: 99 (original description, no species designated [nomen nudum]).

Skeponopodus typus Nardo, 1833: 416-419 (description; type locality: Adriatic Sea). Nardo, 1834: 418 (listed). Bonaparte, 1846: 80 (*S. typus* a synonym of *Tetrapterurus* [sic] *belone*). Canestrini, 1872: 112 (a synonym of *Tetrapturus belone* Rafinesque).

Tetrapterurus belone, Bonaparte, 1841:19 (emended spelling; compared with *Xiphias*). Bonaparte, 1846:80 (listed; *Skeponopodus typus* Nardo a synonym). Nardo, 1847:461-463 (description, comparisons, synonymy).

Tetrapterus belone, Agassiz, 1843:7, 89-90, table E (description of skeleton, figured). Canestrini, 1861b:263 (listed from Taranto). Desbrosses, 1938:48-58, pl. 1, upper figure only (in part; listed from Mediterranean; compared with other species). LaMonte, 1946:32-34 (distribution, color, size, characters). Robins, *1958:16 (Florida, Mediterranean). deBuen, 1958:19 (*Tetrapterus* [sic] referred to synonymy of *Makaira* but combination *M. belone* not used).



FIGURE 1. *Tetrapturus belone* Rafinesque. a) Specimen 4: 1482 mm body length. b) Same as "a," note the forward placement of the anus in this species. c) specimen 16, a juvenile, 540 mm body length.

TABLE 1
FIN-RAY COUNTS OF ATLANTIC SPECIES OF THE FAMILY ISTIOPHORIDAE

Species	Dorsal spines																	Pectoral Rays						
	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	17	18	19	20	21	22	23	
<i>Istiophorus albicans</i>	—	—	1	1	8	4	1	2	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
<i>Tetrapturus belone</i>	—	—	—	—	—	—	—	—	1	2	5	5	3	1	—	1	—	—	—	—	—	—	—	
<i>T. albidus</i>	1	3	8	10	11	9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
<i>Makaira nigricans</i>	—	4	5	6	15	9	6	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	

Species	Anal spines					Dorsal Rays					Anal Rays					Pectoral Rays						
	12	13	14	15	16	17	5	6	7	8	5	6	7	8	17	18	19	20	21	22	23	
<i>Istiophorus albicans</i>	2	7	3	—	—	—	—	3	11	—	1	5	7	2	—	2	6	3	1	—	—	—
<i>Tetrapturus belone</i>	—	1	8	—	1	—	—	10	4	—	—	5	9	—	—	2	6	5	—	—	—	—
<i>T. albidus</i>	—	4	18	18	5	—	20	21	1	—	2	41	—	—	1	2	6	23	9	—	—	—
<i>Makaira nigricans</i>	—	—	8	26	9	2	—	24	15	2	—	13	26	—	—	—	3	8	12	14	1	1

- Tetrapturus belone*, Vérany, 1847:492-494 (Camogli; misprint for *Tetrapturus?*)
- Histiophorus belone*, Günther, 1860:513 (listed from Mediterranean; synonymy, description, color, counts, discussion of species). Gigliogli, 1880 (listed from Palermo). Parona, 1898:368 (rare or accidental in Ligurian Sea; *T. lessonae* Canestrini placed in synonymy in error).
- Scheponopodus prototypus*, Canestrini, 1872:112 (variation in spelling; description). Carus, 1889-1893:676 (a synonym of *Tetrapturus belone* Rafinesque).
- Histiophorus (Tetrapturus) belone*, Lütken, 1876a:60-63, pl. 3 (compared with other species; differences in rostrum and dorsal fin of *Tetrapturus* and *Histiophorus* do not warrant generic distinction; *Tetrapturus* a subgenus of *Histiophorus*).
- Tetrapturus imperator*, Goode, 1882:417-418 and 1883:296, 306-307, 347 (in part; *T. belone* placed in synonymy of *imperator*, a synonym of *Xiphias gladius*, in error).
- ?Young *Makaira*, *LaMonte, 1955:346-347 (fish taken in "Spring of 1939 half-way between Bimini, Bahamas and Miami, Florida").
- Spearfish, Swann, 1957:15, 28 (photograph of specimen captured off Port Aransas, Texas; subsequently reported on by Springer and Hoese [1958] as *Tetrapterus belone* [?], and listed by Hoese [1958] as *Tetrapturus belone*).
- Tetrapterus belone* (?), *Springer and Hoese, 1958:345-346 (Port Aransas, Texas; measurements, counts, coloration).
- Makaira belone*, Tortonese, 1958:330 (new combination; listed, Mediterranean Sea).
- Tetrapturus beloni* (sic), *Briggs, 1958:287 (listed from Florida; distribution, habitat).
- Tetrapterus*, *Robins; 1958:17 (Southeastern Florida). Erdman and Roman, 1959: fig. on p. 117 (Puerto Rico).
- Tetrapturus* sp., Migdalski, 1958:70-71, lower fig. opposite p. 100, except for fish in upper right; (Florida and Texas).

Diagnosis.—Dorsal spines numerous, 46-53, the last few sometimes partially or completely concealed. Spinous dorsal high, dipping slightly at about spine 7 or 8 but then increasing in height again and remaining so for most of its length. Anterior lobe of spinous dorsal somewhat rounded in adults. Pectoral fin in adults long and somewhat curved, its length about 1.1-1.5 in head length (from tip of mandible). Anal-fin height in adults decidedly shorter than height of spinous dorsal above first anal-fin origin. Anterior lobe of anal-fin rounded. Anus far forward (fig. 1b), removed from anal-fin origin by a distance equal to or (usually) greater than height of first anal fin. Profile of dorsum anterior to dorsal-fin origin flattened, without a marked rise at occiput (fig. 1a, c; fig. 2a, b). Body depth at dorsal-fin origin consequently small, its depth much less than the maxillary length. Orbit small, its horizontal diameter contained about 4.1 to 4.5 times in snout length. Body slender, its dorsal and anal profiles nearly parallel over the trunk

length. Smaller specimens slab-sided, larger individuals more robust and round bodied. Twelve precaudal and 12 caudal vertebrae; total 24. Bill decidedly projecting, moderate in length, about equal to the length of the pelvic fins. Premaxillae not completely covering maxillary bones on lower side of bill. Palatine-tooth patches well developed.

Description.—Frequency distributions of fin-ray counts are given in Table 1. Morphometric data are provided in Tables 2 and 3. Only those proportions which the writers deem of special importance need be mentioned here. Graphs depicting the growth of the bill and various measures of body width and depth are presented in Figure 2.

The body is slender throughout. Its dorsal profile slopes gently to the dorsal-fin origin and then is nearly straight to the caudal-fin base. The dorsal and ventral contours are nearly parallel for most of the body length (fig. 1a, c). In specimens shorter than 1500 mm in body length the body is quite slab-sided. Above 1500 mm the species gains weight rapidly and the body is much more rotund (fig 3b).

The anterior height of the spinous dorsal fin is greater than the body depth at the dorsal-fin origin. In small individuals (<1000 mm body length) the fin height is nearly twice the body depth while in large specimens (>1600 mm body length) the fin height only slightly exceeds body depth. The form of the dorsal fin in juveniles is clearly indicated in Figure 1c. In adults the fin is less high posteriorly (fig. 1a). However, the spines of the posterior third of the fin are longer than those behind the anterior lobe, a fact not apparent from the photograph.

The first anal fin is relatively low; its greatest height is less than the distance from the origin of the first anal fin to the anus (fig. 1b). This index is enhanced by the anterior position of the anus.

The pectoral fin shows marked allometry, being small in small specimens (<1100 mm) (fig. 1c). Between 1100 and 1300 mm in body length, the pectoral fin grows rapidly and assumes its adult form. In contrast, bill length is proportionally longer in small specimens. A comparison of the two shows the allometry. In specimens smaller than 1000 mm body length the bill averages twice the length of the pectoral fin, while in large specimens (more than 1300 mm) the two are nearly equal with the pectoral fin averaging slightly larger. The lateral line is simple; the single lateral canal arches in the region of the pectoral fin.

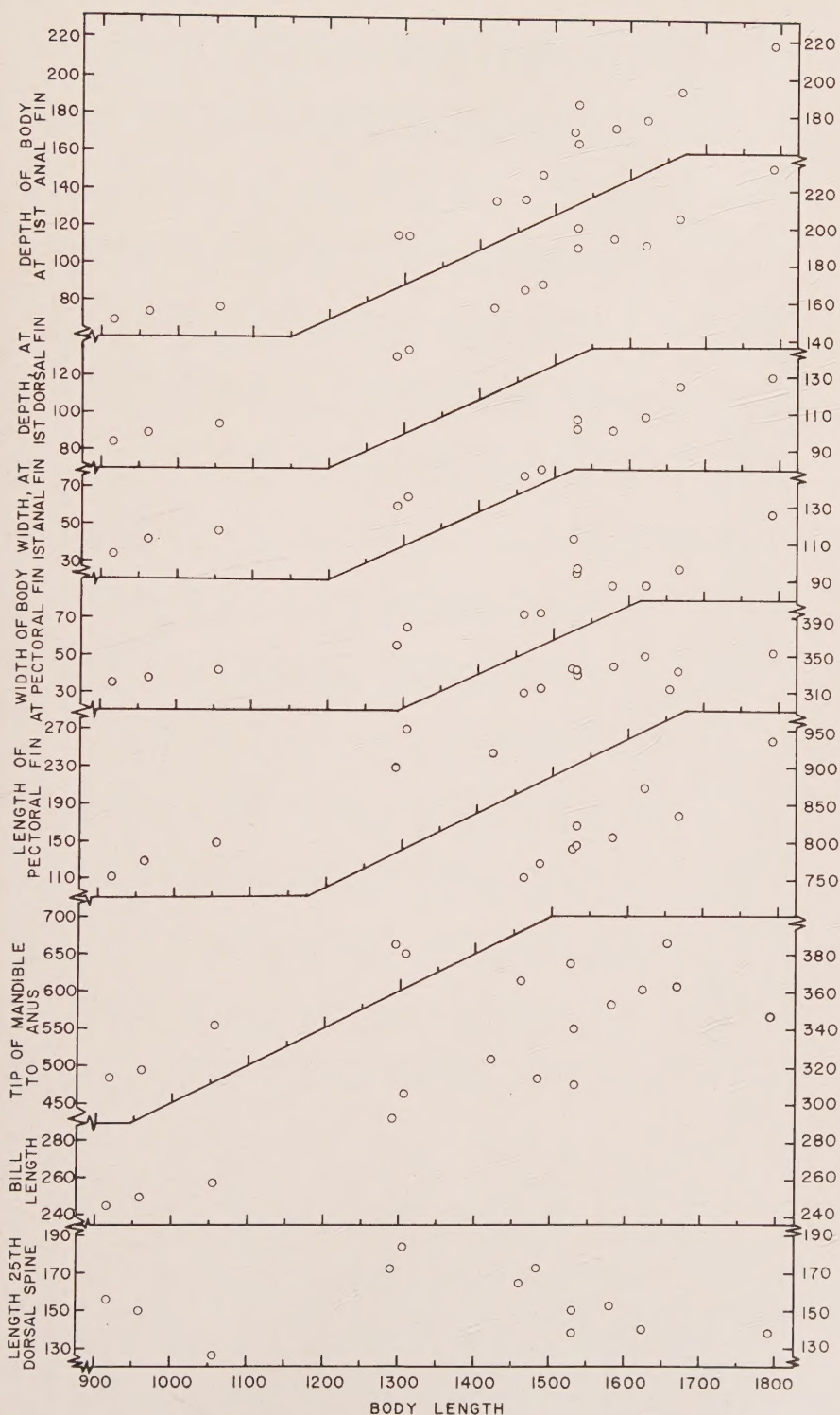


FIGURE 2. *Tetrapturus belone* Rafinesque. Analysis of growth of certain body parts based on data from Western North Atlantic specimens.

TABLE 2

MORPHOMETRIC DATA FOR 15 SPECIMENS OF *Tetrapturus belone* FROM THE WESTERN ATLANTIC. MEASUREMENTS (IN MILLIMETERS) ARE AS DEFINED BY RIVAS (1956a) UNLESS OTHERWISE INDICATED. (NUMBERS IN PARENTHESES REFER TO THE NUMBERED DEFINITIONS OF RIVAS; SEE TEXT ABOVE FOR EXPLANATION OF ABBREVIATIONS).

Character	Specimen No.															
	7	13	12	1	3	10	2	4	9	5	6	14	21	11	8	15
Body length (1)	914	961	1055	1290	1305	1421	1460	1482	1525	1530	1530	1577	1623	1655	1665	1790
First predorsal length (3)	185	—	212	260	269	305	315	313	—	310	322	329	—	351	340	375
Second predorsal length (4)	765	—	881	1052	1073	1144	1190	1243	—	1265	1245	1262	1328	—	1353	1459
Prepectoral length (5)	227	239	258	315	318	360	370	362	—	375	383	398	388	—	391	422
Prepelvic length (6)	238	247	270	326	338	377	387	385	—	395	410	416	412	—	417	453
First preanal length (7)	582	—	662	797	782	918	905	922	—	926	945	966	1025	1075	995	1098
Second preanal length (8)	750	—	865	1022	1045	1150	1145	1195	—	1245	1240	1251	1320	—	1332	1437
Orig. D ₁ to orig. P ₁ (9)	76	83	80	111	117	—	131	137	—	159	164	158	152	—	170	187
Orig. D ₁ to orig. P ₂ (10)	105	106	108	156	153	—	181	180	—	207	220	208	205	—	220	255
Orig. D ₂ to orig. A ₂ (11)	56	65	68	90	95	—	105	115	—	124	132	125	126	—	103	153
Tip mandible to anus	484	495	555	664	650	—	752	773	787	823	793	804	874	—	835	935
Orig. P ₂ to nape (13)	116	—	—	151	—	—	185	—	—	—	—	215	213	—	245	262
Greatest body depth (14)	84	91	94	140	139	—	166	176	188	199	217	195	198	—	220	256
Depth at orig. D ₁ (15)	84	89	94	130	134	156	166	169	—	189	200	194	190	—	205	232
Depth at orig. A ₁ (16)	69	74	76	115	115	134	135	148	171	165	186	173	178	—	193	218
Least depth c.p. (17)	25	—	27	40	—	46	—	—	48	54	55	52	56	—	59	65
Width at P ₁ base (18)	35	38	42	55	65	—	72	73	113	95	97	88	88	—	96	126
Width at A ₁ orig. (19)	34	42	46	60	65	—	76	80	—	102	107	101	109	—	125	130
Width at A ₂ orig. (20)	30	37	—	53	53	—	64	74	—	—	—	83	93	—	91	108
Width c.p. (in front of keels)	22	—	23	36	33	—	34	46	—	—	—	43	42	—	54	51
Length upper keel (22)	26	—	32	49	40	—	44	54	41	57	52	61	47	—	49	53

TABLE 2 (Continued)

MORPHOMETRIC DATA FOR VE SPECIMENS OF *Tetrapturus belone* FROM THE WESTERN ATLANTIC. MEASUREMENTS (IN MILLIMETERS) ARE AS DEFINED BY RIVAS (1956a) UNLESS OTHERWISE INDICATED. (NUMBERS IN PARENTHESES REFER TO THE NUMBERED DEFINITIONS OF RIVAS; SEE TEXT ABOVE FOR EXPLANATION OF ABBREVIATIONS).

Specimen No.																	
Length lower keel (23)	21	—	30	40	40	—	46	52	—	50	51	58	42	—	49	58	
Head length (24)	220	231	250	299	304	346	360	352	365	361	369	378	372	414	375	413	
Snout length (25)	117	—	131	147	156	187	185	182	—	176	180	189	177	—	175	197	
Bill length (26)	245	249	256	292	305	324	366	313	375	310	340	353	362	386	363	337	
Maxillary length (28)	141	148	160	187	204	222	224	226	—	230	230	239	232	—	229	256	
Orbit diameter (29)	22	26	30	34	—	38	—	42	39	42	40	43	44	48	45	47	
Depth of bill (33)	8	—	—	9	10	—	12	12	—	11	10	14	11	—	—	17	
Width of bill (34)	10	11	—	14	12	—	16	18	—	17	16	16	19	—	—	21	
Height D ₁ (39)	154	152	172	215	241	205	235	234	—	230	256	252	230	—	245	270	
Length 25th D ₁ spine (40)	156	150	126	172	184	—	164	172	—	150	138	152	140	—	—	138	
Height D ₂ (41)	29	—	35	45	55	64	49	53	62	60	62	61	61	—	72	65	
Height A ₁ (42)	82	77	92	116	125	135	119	130	126	145	—	168	132	125	105	159	
Height A ₂ (43)	26	—	30	36	—	48	52	—	50	48	60	60	50	—	53	60	
Length P ₁ (44)	113	129	149	230	271	245	310	317	337	335	330	339	350	315	334	352	
Length P ₂ (45)	—	214	250	303	288	327	—	340	330	365	335	324	344	359	333	362	
Length last D ₂ ray	45	—	48	—	—	—	—	—	98	83	92	94	95	—	80	112	
Length last A ₂ ray	46	—	—	—	—	—	—	—	89	90	90	75	91	—	82	110	
Orig. D ₁ to orig. D ₂	580	—	675	—	820	—	913	—	—	961	940	945	1048	—	1040	1110	
Anus to orig. A ₁	102	88	—	130	130	—	145	154	150	129	148	152	157	—	157	164	
Weight (lbs.)	3.5	—	5	12	15	20	19	24	35	32	38.5	34	31	33	45	68	

TABLE 3

MORPHOMETRIC DATA FOR 15 SPECIMENS OF *Tetrapturus belone* FROM THE WESTERN ATLANTIC EXPRESSED IN PERCENTAGE OF BODY LENGTH. MEASUREMENTS ARE AS DEFINED BY RIVAS (1956a) UNLESS OTHERWISE INDICATED. (NUMBERS IN PARENTHESES REFER TO THE NUMBERED DEFINITIONS OF RIVAS; SEE TEXT ABOVE FOR EXPLANATION OF ABBREVIATIONS.)

Character	Specimen No.													
	7	13	12	1	3	10	2	4	9	5	6	14	21	11
Body length (1)	914	961	1055	1290	1305	1421	1460	1482	1525	1530	1530	1577	1623	1655
First predorsal length (3)	19	—	20	20	21	22	22	21	—	20	21	21	—	21
Second predorsal length (4)	84	—	84	82	82	80	82	84	—	83	81	80	82	—
Prepectoral length (5)	23	24	26	24	24	25	25	24	—	24	25	25	24	—
Prepelvic length (6)	24	26	26	25	26	26	26	26	—	26	27	26	25	—
First preanal length (7)	64	—	63	62	60	65	62	62	—	60	62	61	63	65
Second preanal length (8)	82	—	82	79	80	81	78	81	—	81	81	79	81	—
Origin D_1 to orig. P_1 (9)	8.3	8.6	7.6	8.6	9.0	—	9.0	9.2	—	10	11	10	9.4	—
Orig. D_1 to orig. P_2 (10)	12	11	10	12	12	—	12	12	—	14	14	13	13	—
Orig. D_2 to orig. A_2 (11)	6.2	6.8	6.4	7.0	7.3	—	7.2	7.8	—	8.1	8.6	7.9	7.8	—
Tip mandible to anus	53	52	53	52	50	—	52	52	52	54	52	51	54	—
Orig. P_2 to nape (13)	12	—	—	12	—	—	13	—	—	—	—	14	13	—
Greatest body depth (14)	8.4	9.5	8.9	11	11	—	11	12	12	13	14	12	12	—
Depth at orig. D_1 (15)	9.2	9.2	8.9	10	10	11	11	11	—	12	13	12	12	—
Depth at orig. A_1 (16)	7.5	7.7	7.2	8.9	8.8	9.4	9.2	10	11	11	12	11	11	—
Least depth c.p. (17)	2.7	—	2.6	3.1	—	3.2	—	—	3.1	3.5	3.6	3.3	3.4	—
Width at P_1 base (18)	3.8	4.0	4.0	4.3	5.0	—	4.9	4.9	7.4	6.2	6.3	5.6	5.4	—
Width at A_1 orig. (19)	3.7	4.4	4.4	4.6	5.0	—	5.2	5.4	—	6.7	7.0	6.4	6.7	—
Width at A_2 orig. (20)	3.0	3.8	—	4.1	4.1	—	4.4	5.0	—	—	—	5.3	5.7	—
Width c.p. (in front of keels)	2.2	—	2.2	2.8	2.5	—	2.3	3.1	—	—	—	2.7	2.6	—
Length upper keel (22)	2.9	—	3.0	3.8	3.1	—	3.0	3.6	2.7	3.7	3.4	3.9	2.9	—
Length lower keel (23)	2.3	—	2.8	3.1	3.1	—	3.2	3.5	—	3.3	3.3	3.7	2.6	—

TABLE 3 (Continued)

MORPHOMETRIC DATA FOR VE SPECIMENS OF *Tetrapturus belone* FROM THE WESTERN ATLANTIC EXPRESSED IN PERCENTAGE OF BODY LENGTH. MEASUREMENTS ARE AS DEFINED BY RIVAS (1956a) UNLESS OTHERWISE INDICATED. (NUMBERS IN PARENTHESES REFER TO THE NUMBERED DEFINITIONS OF RIVAS; SEE TEXT ABOVE FOR EXPLANATION OF ABBREVIATIONS.)

	Specimen No.																	
Head length (24)	22	24	24	23	23	24	25	24	24	24	24	24	24	23	25	22	23	
Snout length (25)	13	—	12	11	12	13	13	12	—	12	12	12	12	11	—	10	11	
Bill length (26)	27	26	25	22	23	23	25	21	25	20	22	22	22	22	23	22	19	
Maxillary length (28)	15	15	15	14	16	16	15	15	—	15	15	15	15	14	—	14	14	
Orbit diameter (29)	2.4	2.7	2.8	2.7	—	2.7	—	2.8	2.6	2.7	2.6	2.7	2.7	2.7	2.9	2.7	2.6	
Depth of bill (33)	.88	—	—	.71	.77	—	.80	.81	—	.69	.65	.89	.68	—	—	—	1.1	
Width of bill (34)	1.0	1.1	—	1.0	.92	—	1.1	1.2	—	1.1	1.0	1.0	1.2	—	—	—	1.2	
Height D ₁ (39)	17	16	16	17	18	14	16	16	—	15	17	16	14	—	—	15	15	
Length 25th D ₁ spine (40)	17	16	12	13	14	—	11	12	—	9.8	9.0	9.6	8.6	—	—	—	7.7	
Height D ₂ (41)	3.2	—	3.3	3.5	4.2	4.5	3.4	3.6	4.1	3.9	4.0	3.9	3.8	—	—	4.3	3.6	
Height A ₁ (42)	8.9	8.0	8.7	9.0	9.6	9.5	8.1	8.8	8.3	9.5	—	—	11	8.1	7.6	6.3	8.9	
Height A ₃ (43)	2.9	—	2.8	2.8	—	3.4	3.8	—	3.3	3.1	3.9	3.8	3.1	—	—	3.2	3.4	
Length P ₁ (44)	12	13	14	18	21	17	21	21	22	22	22	22	22	22	19	20	20	
Length P ₂ (45)	—	22	24	24	22	23	—	23	22	28	22	20	21	22	22	20	20	
Length last D ₂ ray	4.9	—	4.5	—	—	—	—	—	6.4	5.4	6.0	6.0	5.8	—	—	4.8	6.2	
Length last A ₃ ray	4.9	—	—	—	—	4.8	—	—	5.9	5.9	5.9	4.4	5.6	—	—	4.9	6.1	
Orig. D ₁ to orig. D ₂	63	—	64	—	63	—	62	—	—	63	61	60	65	—	—	62	62	
Anus to orig. A ₃	11	9.2	—	10	10	—	9.9	10	9.8	8.4	9.7	9.6	9.7	—	—	9.4	9.2	

In fresh material the body was silvery below and blue-black above; the demarcation is generally well defined. Bands were present only on two small specimens, and faded after a few days. No bands were noted on larger specimens nor were any reported by the fishermen. The dorsal-fin membrane is unspotted.

The flesh is red in all specimens examined. The testis is Y-shaped, the left side much longer. In one specimen (number 15) the left testis was nearly twice as long as the right. The hind gut proceeds straight to the anus. The only organ extending behind the anus is the gas bladder and it reaches the level of the second anal fin. Thus the organ arrangement is not disrupted by the forward placement of the anus.

Nomenclature.—Our identification of western Atlantic specimens with *T. belone* needs some comment beyond that offered in the introduction. Dr. Carlo M. Maldura of the Laboratorio Centrale di Idrobiologia, Rome, kindly provided the Marine Laboratory with photographs of a spearfish caught in the Straits of Messina in April 1958 (fig. 2a). According to data received from Dr. Antonia Spartà of the Istituto Talassografico di Messina, it weighed about 22 kilograms (48 pounds) and measured 1.90 meters in length (presumably total length). Unfortunately morphometric details of this specimen are unavailable, but the specimen closely resembles western Atlantic specimens.

Recently, a photograph of a "spearfish" was obtained from Dr. Vlaho Cviic, Institut za Oceanografiju i Ribarstvo, Split, Yugoslavia. No details are available but the fish is from the Mediterranean near Split, Yugoslavia. The photograph is poor and the size of the fish is unknown, but both the bill and the pectoral fin are short. If unbroken, the bill is about 14 per cent of body length. The pectoral fin is partly erect but appears to be 12 or 13 per cent of body length. Superficially this fish resembles *angustirostris*. The possibility is raised of *T. belone* being a distinct Mediterranean species or senior synonym of *angustirostris*. In either event a new name will be needed for the species here described as *belone*. For these reasons references in the synonymy above to Western Atlantic specimens are marked with an asterisk. It is equally possible that the Split fish is a small blue marlin (*M. nigricans*). Further discussion without additional information is unwarranted.

Rafinesque's genus was never fully described, nor fully differentiated from *Istiophorus* and *Makaira*. The name *Tetrapturus* was

shortened by him from the correct etymology, *Tetrapterurus* (*tetra*, four, *pteron*, wing, and *oura*, tail). The four caudal keels, two per side, to which Rafinesque alluded are characteristic of the entire family. Rafinesque was concerned with distinguishing his genus from the single-keeled *Xiphias*.

Tetrapturus is correct, Bonaparte's emendation to *Tetrapterurus* notwithstanding. Agassiz's *Tetrapterus*, according to Jordan and Evermann (1926:29) rests on a misunderstanding. *Skeponopodus* Nardo is pre-empted by *Tetrapturus*. The decision of Tortonese (1958) to include *Tetrapturus belone* in the genus *Makaira* is understandable. He considered *T. albidus* as typical of *Makaira*. De Buen (1958:19) also places *Tetrapturus* in *Makaira*, but he considers few characters.

The earliest valid name for the longbill spearfish is *Tetrapturus belone* Rafinesque. The name *X. imperator* Schneider has bothered ichthyologists for years, and was recognized as recently as 1952 (Lozano y Rey) although not for *belone*. According to Cuvier (1829) and Jordan and Evermann (1926:31) plate 21 in Bloch and Schneider (1801) on which Schneider's *imperator* was based was a poor drawing of a juvenile specimen of *Xiphias gladius*, copied from Duhamel (1769: fig. A2) and based on Aldrovandi (1638). Goode (1883) for some unknown reason insisted that Schneider's description of the absence of a single carina meant that it therefore had two carinae, and that it was therefore an earlier name for *T. belone*. LaMonte (1955:347) has discussed this name in some detail and considers that "the specimen can never be definitely identified." Actually Schneider (Bloch and Schneider, 1801: xxix and 93) clearly states that his account is strictly based on Duhamel. Duhamel's account is of a swordfish despite the pelvic fins included on one of his two drawings.

Skeponopodus typus Nardo has been placed by several authors in the synonymy of *T. belone*, but, because Rafinesque's type was evidently a juvenile, it is difficult to make direct comparison between the specimens of Nardo and Rafinesque.

The identity of *T. georgii* Lowe (1840a:36) from Madeira will probably never be solved. Lowe's original description states that ". . . the pectoral fins proportionally twice as long [as in *belone* Rafinesque] and the body clothed with large scales of a peculiar shape and nature." Lowe's promise to describe more fully the species

was not fulfilled for subsequent papers (Lowe, 1840b:93; 1849:3) merely repeated the original account.

Further, a survey of the literature reveals no certain record of *belone* from the eastern Atlantic, exclusive of the Mediterranean Sea. LaMonte (1955:347-348) discusses this problem at some length. We consider *T. georgii* Lowe a questioned synonym of *T. albidus*, which it predates.

Tetrapturus lessonae Canestrini (1861a:259-261, pl. 17) was placed by LaMonte (1955:331-332) in the synonymy of the white marlin, *T. albidus*. We confirm this allocation.

MATERIAL EXAMINED

"Photo" indicates that a photograph is on file at The Marine Laboratory, University of Miami. All lengths are body lengths.

UMML 5955, an adult, 1790 mm, caught by M. A. Madden on June 1, 1958 East of Miami Beach, Florida, photo (spec. 15). UMML 2231, an adult, 1530 mm, caught by R. E. Maytag off San Juan, Puerto Rico, October 1, 1957, photo (spec. 5). UMML 2230, a juvenile, 914 mm, caught off Palm Beach, Florida, March 23, 1958, photo (spec. 7). UMML 5956, an adult, 1665 mm, caught 1.5 miles off Hillsboro Light, Florida, late December 1957 or early January, 1958, (spec. 8). UMML 3484 (skeleton only) 1482 mm, caught off Miami, Florida, August 14, 1957, by S. Bergman, photo (spec. 4).

Additional material examined (specimens no longer available).

Spec. 1: 1290 mm, female, off Marathon, Monroe Co., Florida, May 5, 1957, caught by Mr. C. V. Underwood, photo.

Spec. 2: 1460 mm, male?, off Islamorada, Monroe Co., Florida, May 5, 1957, caught by F. L. McCool, photo.

Spec. 3: 1305 mm, sex ?, off Ft. Lauderdale, Florida, June 2, 1957, caught by J. B. Richer, photo.

Spec. 6: 1530 mm, sex ?, off Miami, Florida, November 9, 1957, caught by J. T. Huish.

Spec. 9: 1525 mm, male, off San Juan, Puerto Rico (data received from Donald S. Erdman).

Spec. 10: 1421 mm, female, off Ocean City, Maryland, August 12, 1957 (data received from Robert H. Gibbs, Jr.).

Spec. 11: 1655 mm, immature female, 9 mi. south, southeast of Port Aransas, Texas, caught by Robert L. Ladd, photo (data received from Victor G. Springer).

Spec. 12: 1055 mm, sex ?, 8 miles off Ft. Lauderdale, Florida, May 9, 1958, caught by Mrs. Frank White.

Spec. 13: 961 mm, sex ?, off Palm Beach, Florida, March 3, 1956.

Spec. 14: 1577 mm, male, off Ft. Lauderdale, Florida, September 25, 1958, caught by J. Steiert.

Spec. 21: 1623 mm, mature female, off Baker's Haulover, Dade Co., Florida, caught by R. J. Mallin, photo (photo in the Miami Herald, December 9, 1959: 7c).

Additional records based on photographs sent to the Marine Laboratory.

Spec. 16: 540 mm approximately, off Miami, Florida, details unknown (data Al Pflueger).

Spec. 17: length (total?) 7'6", wt. 58.5 lbs. off Palm Beach, Florida, caught by F. H. Magnus, date unknown (photograph from Capt. J. Harms, and from Outdoor Life, 1955).

Spec. 18: Length 74 inches, wt. 30 lbs., off Miami Beach, Florida, February 27, 1956, caught by W. Rudbart (data from Al Pflueger).

Spec. 19: North Central Gulf of Mexico, December 1954, photograph of *T. belone* and *T. albidus* on deck of M/V OREGON (photographs from Harvey R. Bullis, Jr.). (During December 1954, the OREGON operated longline stations 1217, 1219 and 1221, from lat. 26°36' to 27°55'N, and from long. 88°20' to 88°45'W.)

Spec. 20: Juvenile, off Orchila Island, Venezuela, September 10, 1959, caught on longline by commercial fisherman (data from J. P. Phelps, Jr., with additional statement that several were also taken 20 miles off La Guaira, Venezuela).

Finally Frank J. Mather III of Woods Hole Oceanographic Institution sent information on two fish (body length about 1690 mm) taken at M/V OREGON Station 1290 (lat. 16°15'N, long. 73°30'W, April 20, 1955, longline) which he thought might be spearfish. An accompanying diagnosis allows us to confirm this identification.

Addendum.—After this paper was in press three additional specimens were seen through the courtesy of Miss Francesca LaMonte and Mr. Joseph T. Reese. Distributional data were added to Figure 4 but it was too late to add to the Tables or to Figure 3.

Spec. 21: 1740 mm, female, lat. 12°38'N, long. 69°17'W, M/V OREGON Station 2764, April 10, 1960.

Spec. 22: 1620 mm, female, lat. 12°36'N, long. 63°40'W, M/V OREGON Station 2768, April 14, 1960.

Spec. 23: skin only, said to have measured 89 inches (total length?) and weighed 49 lbs., off Mississippi Delta, Louisiana, June 1, 1960, K. A. Gibson. Recent correspondence from Mr. Gibson confirms these data and places the capture point about 35 miles due south of South Pass of the Mississippi River.

DISCUSSION

Comparison.—*Tetrapturus belone* has been confused with other istiophorids. In the Miami region, anglers usually mistake small individuals for sailfish (*Istiophorus albicans*), undoubtedly due to the high dorsal fin that the young spearfish possesses (fig. 1c). Large specimens are landed as white marlin (*Tetrapturus albidus*) because of the large pectoral fin and the fact that it is not a blue marlin (*Makaira nigricans*). Actually, *belone* is easily distinguished from such species at any size. It differs from all Atlantic istiophorids in the anterior placement of the anus and the high number (46-53) of dorsal spines. A comparison of *T. belone* and *T. angustirostris* is given under the account of *angustirostris*. From the sailfish it is further distinguished

by the lower dorsal fin. Even in juvenile longbill spearfish, the dorsal fin is not elevated in sailfish fashion (see Beebe, 1941, pl. 5). The eye of *T. belone* is larger (2.4-2.9 per cent of the body length) than in *I. albicans* (1.9-2.4) and smaller than in *T. albidus* (3.1-3.4). The pectoral fin in *I. albicans* is small even in adults (14-19 per cent of body length; adults of *T. belone* 19-22; adults of *T. albidus* (19-25). The dorsal profile of both the sailfish and the white marlin rises sharply above and behind the eye (fig. 3c). Thus these species have a characteristic dorsal hump in front of the dorsal fin whereas this region is even in longbill spearfish from the dorsal-fin origin to well in front of the eyes, and in smaller specimens to the bill tip.

The longbill spearfish differs from the white marlin (fig. 3c) but not the sailfish in having a lower first anal fin (spearfish, 6.3-11 per cent; sailfish, 8.6-11; white marlin, 11-16). Also the anterior lobe of the first anal fin is broadly rounded in the white marlin, pointed in the sailfish and intermediate in the longbill spearfish.

The spinous dorsal fin of the white marlin and sailfish is spotted (these fade after death) while the longbill spearfish fins are plain. The large pectoral fin of the white marlin is curved along its dorsal profile and round at its tip. The longbill spearfish has a straighter fin with a more pointed tip and the sailfish has a small, curved and pointed fin.

The blue marlin, *Makaira nigricans* Lacépède, is a very distinct species. It differs in having a complex lateral line (see LaMonte 1958a, fig. 4, and de Sylva, 1958, pl. 81), a distinct vertebral count (11 precaudal and 13 caudal vertebrae), a low dorsal fin, its anterior height less than the body depth, a pointed dorsal lobe, and pale flesh. The bill shows positive allometry, being much longer and more robust in the adult than in the juvenile (de Sylva, 1958, pl. 81, fig. 2 and pl. 82). The juvenile blue marlin shows a marked but superficial resemblance to the shortbill spearfish, *Tetrapturus angustirostris* Tanaka (compare, for example, pl. 81, fig. 2 of de Sylva [1958] with fig. 1 of Craig [1958]). The blue marlin also reaches a large size (reputedly to 2000 lbs. both in the Atlantic and Pacific). The larva referred by Gehringer (1957:169, fig. 25) to *Tetrapturus* is probably *Makaira nigricans* as suggested by Ueyanagi and Yabe (1959: 151).

Distribution.—Figure 4 summarizes the known records of *Tetrapturus belone* from the western north Atlantic. The records range from Maryland to Texas and to Puerto Rico and Venezuela. Most records

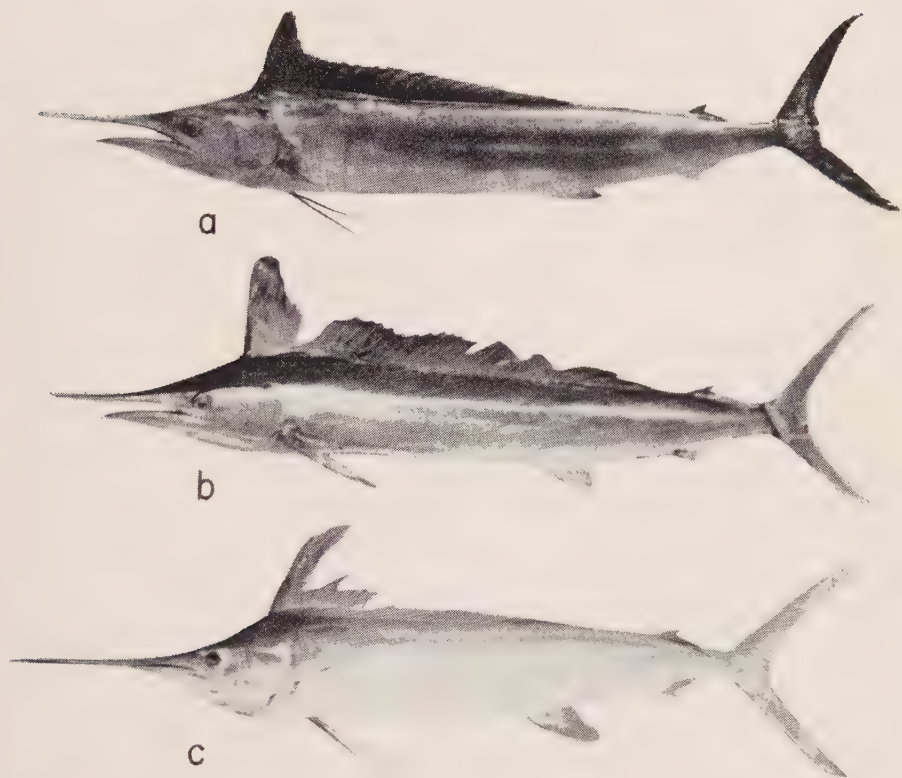


FIGURE 3. a) *Tetrapturus belone* Rafinesque, 48 lb. adult, length (total?) 1.9 meters, caught in the Straits of Messina, Mediterranean Sea, in April, 1958. (photograph courtesy of Dr. Carlo M. Maldura). b) UMML 5955, body length 1790 mm, wt. 68 lbs, spec. 15, the largest specimen of *T. belone* yet taken in the Western Atlantic. c) *Tetrapturus albidus* Poey, adult male 1606 mm body length, wt. 58 lbs., caught off Miami, Florida, February 22, 1959.

are from the Florida Keys, perhaps a reflection of more intensive fishing effort. John Christiansen, of Miami, who is familiar with the species, reports the spearfish from La Guaira, Venezuela, on September 10 or 11, 1959. The presence of the species along the Venezuelan coast is confirmed by a photograph forwarded from John P. Phelps, Jr., of a fish caught at Isla Orchila. In addition, it occurs in the Mediterranean Sea (except for the eastern end?). Presumably it will be found elsewhere in the eastern temperate and tropical Atlantic. The numerous records of (longbill) spearfish from the

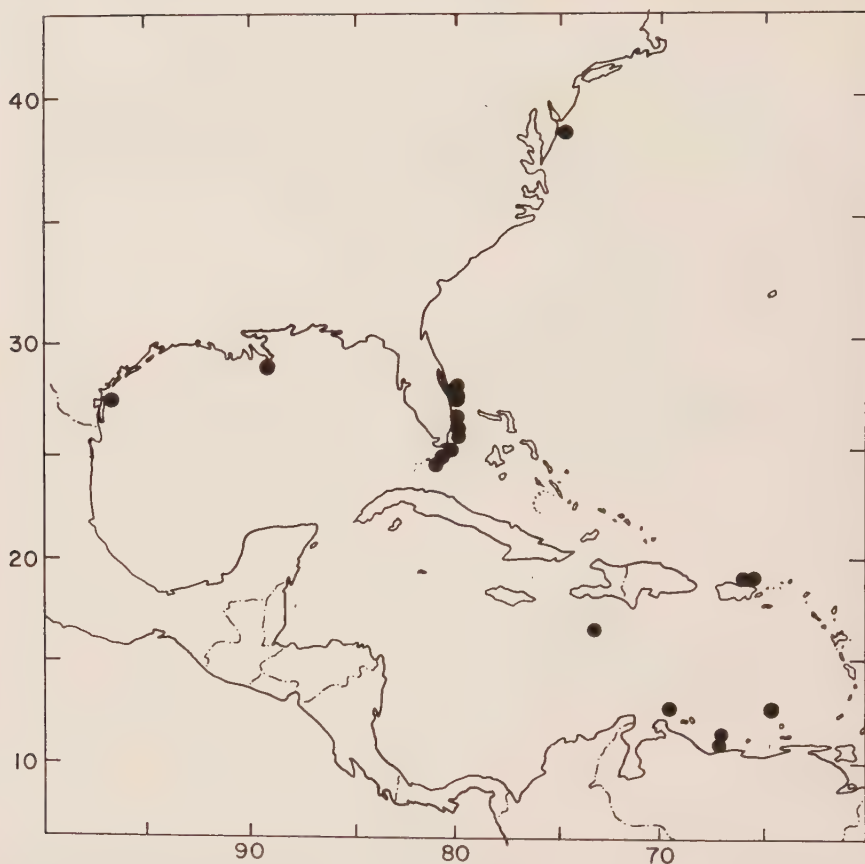


FIGURE 4. Distribution of *Tetrapturus belone* Rafinesque in the Western North Atlantic. See material examined section for definite locality information and for the basis of individual records.

eastern Atlantic are based on the white marlin (e.g., Legendre, 1928: 391-392, fig. 1; 1935:30-31; Lozano Cabo, 1958:57, fig. 93) and the blue marlin (e.g., Lozano Cabo, 1958:57, fig. 94).

Relationships.—The limits of the genus *Tetrapturus* are ill-defined in current literature, perhaps due in part to the prior lack of information about the type species *belone*. Nakamura (1949 and English translation, 1952) divided the Istiophoridae into two subfamilies Tetrapturinae and "Marlinae" (=Makairinae). Other workers either overlooked or failed to follow this lead. *Makaira*, as currently constituted,

bridges this break and is unnatural; its species are in part assigned to *Tetrapturus* below. We agree with the basic dichotomy suggested by Nakamura although the divisions need not be designated subfamilies. To the definitions of Nakamura (1938, 1949) we add the character of negative allometry of the bill in the "Tetrapturinae" versus positive allometry in the "Makairinae." Also the "Tetrapturinae" are small species, generally much less than 300 lbs. while the two members of the "Makairinae" reach about 2000 lbs. The world-record "striped marlin," a 692 lb. individual taken off Balboa, California, August 18, 1931, is a blue marlin, *M. nigricans*.

LaMonte (1955:325) separated *Tetrapturus* from *Makaira* largely on the basis of the length of the pectoral fin. As already noted, the pectoral fin shows marked allometry in the spearfish. Also, *Tetrapturus*, as here constituted, includes one species (*angustirostris*) that apparently has a short pectoral and several species with very long pectorals; therefore this feature will not aid generic definition.

T. angustirostris, *belone*, *albidus* and *audax* form a series of equally distinct species. In some ways, but not in numbers of first dorsal elements and position of anus, the middle two resemble each other more closely than either *angustirostris* or *audax*. The placement of *albidus* and *audax* in *Makaira* by recent authors is not in accordance with their relationships. In any scheme they must be more closely associated with *angustirostris* and *belone* and indeed with *Istiophorus* than with any of the Makairinae. Japanese workers follow Nakamura in placing *audax* in *Kajikia*, which becomes a monotypic genus since the second species *K. formosana* Nakamura is a synonym of *audax* (based on a juvenile specimen). Smith (1956:32) further divided the group by placing *albidus* in *Lamontella*. We feel that the four species are equally distinct and that the characters separating them do not deserve generic or even subgeneric rank. Therefore, we recognize four species in the genus *Tetrapturus*: *T. belone* Rafinesque, *T. angustirostris* Tanaka, *T. albidus* Poey and *T. audax* Philippi. The synonymy of *Tetrapturus* was given above.

The relationships of *Tetrapturus* are with *Istiophorus* rather than *Makaira* as here restricted. Our concept of the phylogeny of the Istiophoridae is diagrammed in Figure 5. The species of *Istiophorus* are poorly known but it already appears that few species are represented. The only characters separating *Istiophorus* from *Tetrapturus* are the form of the dorsal fin and the nature of the pelvic fins. Even the

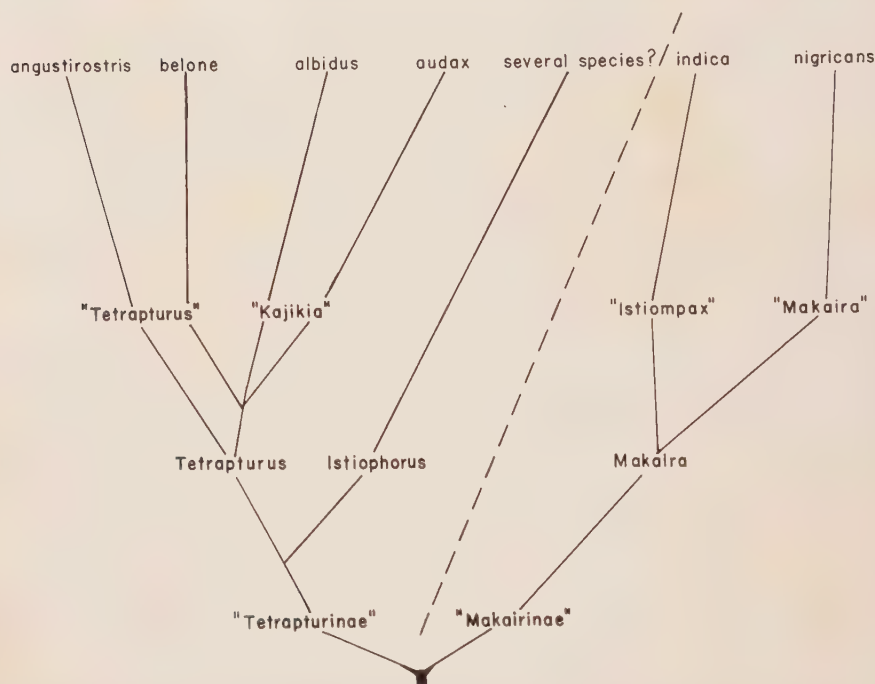


FIGURE 5. Phylogenetic relationships of fishes of the family Istiophoridae. Names in quotations are not employed by the present writers.

character of the dorsal fin breaks down for when all species are considered *T. belone* and *T. angustirostris* are somewhat intermediate. Moreover the young of all included species have high dorsal fins, but this feature is extreme in *Istiophorus*. The structure of the pelvic fin has been insufficiently investigated. We choose to retain *Istiophorus* and *Tetrapturus* as genera but a case could be made for ranking them as subgenera.

Notes on *Tetrapturus angustirostris* Tanaka.—Royce (1958:520-522, app. tables 1-A, 2-A) summarized the literature on the shortbill spearfish and provided distributional and morphometric data based on central Pacific specimens. Later, Craig (1958:275-280) gave details of a specimen caught off Baja California (lat. 32°05'N., long. 118°14'W.). The known range of *angustirostris* in the eastern Pacific may be further extended. On April 15, 1958, Mrs. John A. Manning collected an 88 pound specimen off Coquimbo, Chile, lat. 30°12'S.,

long. $72^{\circ}00'W$. The specimen, an unripe female, was skinned, subsequently mounted and is now at the Marine Laboratory. The following measurements, in mm (per cent of body length in parentheses) are available: body length, 1822; girth, 690; head length, 420 (23); snout length, 195 (11); bill length, 227 (12); maxillary length 258 (14); orbit diameter, 49 (2.7); depth of bill, 12 (.66); width of bill, 16 (.88); height D_1 , 260 (14); height A_1 , 190 (10); length P_1 , 280 (15); anus to orig. A_1 , 175 (9.6); Counts are: D_1 - 50, D_2 - 6, A_1 - 13? A_2 - 7.

T. angustirostris also occurs in the Indian Ocean. One taken at lat. $25^{\circ}13'S$, long. $99^{\circ}83'E$. (see Yabe *et al.*, 1958:32) is apparently the most western record of the species.

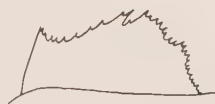
Data obtained from one specimen may not be stressed. Comparison of the percentages given above with those listed for larger specimens of *belone* (table 3) is instructive, however. The only important differences are in the length of pectoral fin and in the bill length (both much shorter in *angustirostris*). The bill does seem narrower but this may be a function of its shortness. The first anal fin may be higher in *angustirostris*. Examination of the literature, especially Craig (1958), Royce (1958) and Tanaka (1914, 1915) and figures therein and elsewhere, substantiates the differences in shortness of bill and pectoral fin. Although the pectoral fin is allometric in *belone*, becoming much larger in adults, the Chilean specimen of *angustirostris* is even larger, which strengthens the difference.

Two important characters are shared by *belone* and *angustirostris* and in these characters they differ from all their allies: 1) A high dorsal spine count; 50 (above), 49-Craig (1958:277), 49-Tanaka (1915:325). 2) An anteriorly placed anus; distance from anus to the origin of the anal fin 7.6-11 per cent of body length in *belone* and 9.6 in *angustirostris*. The flattened profile from the spinous dorsal to the bill tip and the lack of spots in the dorsal fin are additional characters that are probably important.

Royce (1958:522) placed *T. illingworthi* Jordan and Evermann and *T. kraussi* Jordan and Evermann in the synonymy of *T. angustirostris*. We agree with these allocations.

KEY TO ADULTS OF THE SPECIES OF ISTIOPHORIDAE,
EXCLUSIVE OF *Istiophorus*

- A. Spinous dorsal fin strongly elevated, the middle rays decidedly the longest. sailfishes, *Istiophorus* (several species?)



- A. Dorsal fin moderately elevated or not elevated, the middle rays sometimes equal to the anterior ones or much shorter B
- B. Anterior lobe of spinous dorsal fin higher than body depth at dorsal-fin origin, the lobe portion often rounded; 12 precaudal and 12 caudal vertebrae, flesh red (except in *audax*); size small usually much less than 300 lbs. *Tetrapturus* D
- B. Anterior lobe of spinous dorsal fin low, pointed, less than body depth, considerably so in large individuals; 11 precaudal and 13 caudal vertebrae; flesh pale; size large reaching 2000 lbs. *Makaira* C
- C. Pectoral fin rigid, nearly immobile; lateral line simple; chambers of gas bladder in several tiers. black marlin, *Makaira (Istiompax) indica* Cuvier
- C. Pectoral fin depressible; lateral line complex, forming hexagons on the body (difficult to see in large fish); chambers of gas bladder in one tier (except for a few isolated chambers) blue marlin, *Makaira (Makaira) nigricans* Lacépède
- D. Spinous dorsal fin high throughout, the posterior rays about equal in height to the anterior lobe; anus in front of anal-fin origin by a distance equal to or greater than the anal-fin height; dorsal profile from dorsal-fin origin to near tip of bill, straight; dorsal fin unspotted, body bands absent or faint; premandibular portion of bill shorter than distance from tip of mandible to eye; dorsal spines more than 46 E
- D. Spinous dorsal fin low posteriorly, except in small juveniles; anus closer to anal-fin origin, the distance between them decidedly less than anal-fin height; dorsal profile strongly arched over and behind eyes except in very small juveniles; dorsal fin spotted, the spots fading after death but usually apparent in dorsal groove; body bands prominent; premandibular portion of bill longer than distance from tip of mandible to eye; dorsal spines fewer than 46 F
- E. Bill short, only slightly exceeding length of lower jaw, premandibular portion of bill contained three times or more in preorbital distance; pectoral fin short, decidedly shorter than pelvic fin length; Indo-Pacific. shortbill spearfish, *Tetrapturus angustirostris* Tanaka
- E. Bill long, decidedly longer than lower jaw, premandibular portion of bill contained less than three times in preorbital distance; pectoral fin long in adults, almost equal to pelvic fin in length; Atlantic. longbill spearfish, *Tetrapturus belone* Rafinesque
- F. Tips of spinous dorsal, anal and pectoral fins strongly rounded; flesh red; Atlantic white marlin, *T. albidus* Poey
- F. Tips of spinous dorsal anal and pectoral fins pointed; flesh pale; Indo-Pacific striped marlin, *T. audax* Philippi

SUMMARY

The longbill spearfish, *Tetrapturus belone* Rafinesque, is recorded in the Western North Atlantic from Maryland and Texas to Puerto Rico

and Venezuela. Most of the twenty-two records are from southeastern Florida.

The species is described on the basis of this material and its relationships are discussed. The white and the striped marlin are placed in the genus *Tetrapturus* as *T. albidus* and *T. audax* respectively. As reconstituted, *Tetrapturus* includes four species (the three already mentioned and *T. angustirostris* Tanaka), *Makaira* includes two species (the blue marlin, *M. nigricans* [= *M. ampla* of the most recent authors] and the black marlin, *M. indica* [= *Istiompax marlina* or *M. marlina* of the most recent authors]) and *Istiophorus* an uncertain number of species. A phylogenetic tree is presented and a key is offered to the fishes of the family Istiophoridae. Synonymies are provided for *Tetrapturus* and for *T. belone*.

Tetrapturus angustirostris, the shortbill spearfish, is recorded from off the Chilean coast for the first time. The species is briefly discussed and is compared with *T. belone*. All Atlantic istiophorids are compared with *T. belone*.

T. belone may be readily identified by the following combination of characters: the high number of spines in the first dorsal fin, the form of the spinous dorsal fin, the anterior placement of the anus, the bill length and the form and height of the first anal fin.

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LINCKIA BULLISI, A NEW ASTEROID FROM THE NORTHEAST COAST OF SOUTH AMERICA

DONALD R. MOORE¹
Gulf Coast Research Laboratory
Ocean Springs, Mississippi

ABSTRACT

Among invertebrates collected by the Fish and Wildlife Service M/V OREGON from the shelf off the Guiana coast of South America was a new species of starfish, *Linckia bullisi*. It is characterized by a small disk, slender arms, a few greatly enlarged dorsal plates, and by conical spines on some of the marginal plates. Two other species of the genus (*L. guildingii* and *L. bouvieri*), which differ in several details from *bullisi*, are found in the tropical Atlantic.

INTRODUCTION

The U.S. Fish and Wildlife motor vessel OREGON, under the direction of Harvey R. Bullis, Jr., made an exploratory fishing cruise off the Guiana coast of South America during the summer of 1958. Much of the work was done with a shrimp trawl on the continental shelf, and a large number of interesting animals were captured. Among this material was a single striking specimen of a new asteroid of the genus *Linckia*. Two other well known species of this genus are widely distributed throughout the tropical Atlantic.

Linckia bullisi, new species

FIGURE 1

Holotype. OREGON station 2245, August 31, 1958. Latitude 8°15' N, longitude 58°17' W. Depth 39 to 50 fathoms. USNM E-8120.

A five-armed species with slender, cylindrical arms; R 40 mm, r 5 mm, $R/r = 8$; one madreporite; much of the dorsal and lateral surface covered by large prominent plates which are largest on the disk and proximal parts of the arms; entire animal covered with fine granules; papulae in small clusters of three or four on the bare parts of the arms; no pedicellariae; color in formalin light purple; dorsal and lateral plates white, madreporite tan; pale tan underneath. Photographs of both *L. bullisi* and *L. bouvieri* of approximately the same size are included.

The disk is small and is nearly covered by a circle of five plates.

¹Present address: The Marine Laboratory, University of Miami.



FIGURE 1. Upper. *Linckia bouvieri* Perrier, dorsal and ventral views. Lower. *Linckia bullisi*, holotype, dorsal and ventral views.

The position of the plates corresponds with the arms, and, in fact, the distal portions of the plates extend out slightly onto the arms. These plates are barely separated, except for the two adjacent to the madreporite, which are joined. The madreporite, much smaller than the plates, fits up against the two adjacent dorsal plates. The central area of the disk is intermediate in size between the madreporite and the plates. The anal aperture, surrounded by inwardly pointing, closely oppressed granules, is visible in a slightly off center position.

The dorsal surface of the arms has a single row of two to four large plates. Distally, this row breaks up into a number of irregularly

arranged smaller plates. An irregular row of plates, considerably smaller than the large dorsals, is found on the sides of the arms. These plates usually have one or two small conical spines. Distally, these plates become much smaller, and, on the outer one-fourth or one-fifth of the arm, become a rather regular row of superomarginals. On the proximal portion of the arm, the superomarginals are somewhat indistinct. The inferomarginals, however, form a regular distinct row of small plates along the entire length of the arm. Some of these plates on the distal two-thirds of the arm have a small conical spine protruding from the center of the plate.

The ventral surface is covered by small subequal granules. The ambulacral armature is very similar to that found in *Linckia bouvieri* Perrier (1875). It consists of an inner row of short, alternating, slender and broad flat spines. In the second row, behind each pair, is one short, broad and thick spine.

Remarks.—This is the third species of *Linckia* to be found in the tropical Atlantic. *L. guildingii* Gray is a shallow water species, and does not have enlarged dorsal plates. It often reproduces by automotous division, and may have anywhere from four to seven arms. It may also have two or more madreporites. *L. bouvieri* Perrier is found in deeper water, from 6 to about 250 fathoms. Some dorsal plates are enlarged, and there is an irregular number of these on the disk. Usually, however, there is an enlarged plate at the base of each arm, and another is on the proximal side of the madreporite. These plates are usually separated by a space slightly larger than the plates. Marginal plates form two regular rows, and, usually, none are conspicuously enlarged. There are no spines on the plates such as are found on *L. bullisi*.

This species is named for Harvey R. Bullis, Jr.

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CHAETODON GONIODES, A NEW BUTTERFLY FISH FROM PUERTO RICO

LOREN P. WOODS

Chicago Natural History Museum

ABSTRACT

A description is given of a new species of butterfly fish, based on a single specimen, trawled in deep water (125 fathoms) in Mona Passage off western Puerto Rico. The account includes a list of associated deep water fishes and a brief discussion of its relationship with three other species of butterfly fishes.

INTRODUCTION

During Cruise 62 in September-October, 1959, the U. S. Fish and Wildlife Service M/V *Oregon* made 13 trawling stations at various depths in Mona Passage off the west coast of Puerto Rico, Greater Antilles. In the same trawl, Oregon Sta. 2655, the only known specimen of the new butterfly fish was taken along with the following species: *Osteichthys trachypoma* (Günther), *Gephyroberyx darwini* (Johnson), *Polymixia lowei* Günther, *Apogon planifrons* Longley and Hildebrand, *Paracentropristes pomospilus* Ginsburg, *Prionodes atrobranchus* Cuvier, *Antigonia combatia* Berry and Rathjen and *Decodon puellaris* (Poey). It was most surprising to find a butterfly fish at this depth (125 fathoms) associated with this assemblage of deepwater fishes. The maximum depth reported for a related species, *Chaetodon aya* Jordan, is 75 fathoms, most specimens having been taken between 25 and 50 fathoms. Species of the genus *Chaetodon* are usually found at depths of less than 25 fathoms.

Chaetodon goniodes, new species

Holotype: USNM 186318, Oregon Station 2655, off west coast of Puerto Rico, 18°26'N, 67°11'W, 125 fathoms, October 6, 1959. Standard length 95 mm.

Diagnosis. Snout produced, snout and head profile concave; patch of enlarged scales on anterior sides of body, long, strong dorsal spines; color pattern consisting of three oblique bands, a broad band from dorsal fin to eye continued on snout as narrow band to maxillary, a broad band from middle spiny dorsal to tips of anal soft rays, a third narrow band or streak across base of soft dorsal with a narrow bar across caudal peduncle; these bands have narrow yellow borders; inner rays of pelvics very dark brown.

Description. Dorsal fin rays XIII, 19; anal rays III, 15; pectorals 15 (I, i, 13); peivics I, 5; caudal i, 8-8, i; scales 34 from above base of pectoral to middle caudal base, 11 between origin of dorsal and lateral line, 15 between lateral line and anal opening; 31 scales with tubes in lateral line; gill rakers short $5 + 1 + 11$.

Depth of body 1.70, length of head 2.95, snout 6.78, eye 8.63, interorbital 10.0, upper jaw 9.22, depth of caudal peduncle 9.5, length of caudal peduncle 10.8, length of third dorsal spine 3.38, length of middle caudal rays 5.12, length of second anal spine 4.28, length of pectoral fin 3.72, length of pelvic fin 3.39, all in standard length; angle of upper profile with lengthwise axis of body 41 degrees, profile concave. Posterior tip of maxillary extending to vertical below anterior nostril.

Preopercle with shallow concave margin just above angle, preopercle very finely serrate on both limbs, serrae slightly larger at angle; preorbital and rostral also very finely serrate; dorsal orbital bony rim with fine serrae on anterior portion.

Spiny dorsal fin high anteriorly, the first spine less than half the



FIGURE 1. Lateral view of the holotype (and only known specimen) of *Chaetodon goniodes*, USNM 186318, 95 mm in standard length, collected off western Puerto Rico, OREGON Station 2655.

height of second, the second about two-thirds the height of the third, third and fourth spines subequal and the remaining spines successively shorter, the last spine shorter than the first soft rays; outline of soft dorsal convex, caudal truncate; second anal spine longest and strongest, soft anal convex; pectoral fin reaching to 11th scale on sides in row counting from upper edge of gill opening; pelvic fins reaching just past anal opening.

Eight horizontal rows of scales on sides enlarged forming a conspicuous patch covering sides from just behind cleithral bones to oblique body band; lateral line incomplete with apex of arch under 9th dorsal spine and tubes ending at base of 8th dorsal soft ray.

Color. Diagonal dark brown band, about three-fourths the width of the eye, extending from anterior portion of spiny dorsal to eye; forming a broad junction with its fellow on nape in front of dorsal origin; ocular band continued on snout faintly, about as wide as pupil, oriented obliquely forward on preorbital to posterior tip of maxillary, not onto or below maxillary; ocular band above eye bordered posteriorly by prominent yellow line one row of scales in width and anteriorly by a faint, indefinite pale line; a second dark diagonal band, broader than ocular band, extending across body from bases of 3rd-7th dorsal spines to tips of anterior anal rays, bordered both anteriorly and posteriorly by prominent yellow lines, forming an angle of 60 degrees with ocular band; a third dark streak, narrower than the other two bands, running submarginally on the membranes of the posterior dorsal spines, curving ventrally along the basal half of the soft dorsal, continued as a very narrow, slightly diagonal band across caudal peduncle, a faint pale line along the distal margin of this streak on soft dorsal fin portion but not on caudal peduncle; a median stripe on head from interorbital area to tip of snout; snout, interorbital and nuchal area tan where not covered by dark bands; cheeks white, opercle dusky silver, sides white, each enlarged scale with central portion pearly, in largest scales pearly spot rectangular; scaly sheath of posterior spiny dorsal and anterior half of soft anal yellow; caudal fin pale hyaline except for faintly dusky tips of outer rays; pectoral pale with dorsal margin of upper rays dusky; pelvic spine and first ray yellow, inner rays and their membranes black.

Discussion and Relationships. *Chaetodon goniodes* is strikingly like *C. aya* Jordan in several features of its color pattern and the two species appear to be more closely related to each other than either is to any other species. The shape of head and body and the number of

fin rays except caudal rays are essentially the same. The number of principal caudal rays, 18 (16 branched), is one more than in most ordinary spiny-ray fishes. Dr. C. L. Hubbs suggests (in letter) that if this is not an abnormality the greater number of caudal rays may help to indicate the primitive nature of the family. *Chaetodon goniodes* differs in color pattern from *aya* and all other species of *Chaetodon* whose scales are similarly oriented in the patch of enlarged scales on the anterior part of the sides. The dorsal spines are shorter and stronger than those of *aya*, resembling the dorsal spines of *C. marcellae* Poll. The extension of ocular band on the snout is more oblique than in *aya*, of about the same orientation as *marcellae*, not so nearly horizontal as in *C. falcifer* Hubbs and Rehnitzner. Other color differences of *goniodes* are the presence of the streak across the soft dorsal base, the bar on the caudal peduncle and the close proximity of the dorsal portions of ocular and body bands, which are less than diameter of the eye apart (in *aya* these two bands are separated by a distance of more than two eye diameters and the soft dorsal streak and caudal peduncle bar are lacking). The diagonal body band covers only the scaly basal portion of the anal rays in *aya* and covers all but the posterior three anal rays in *goniodes*. The inner pelvic rays are faintly dusky in some *aya*, never so definitely dark brown as in *goniodes*.

Hubbs and Rehnitzner (1958: 300-304) have considered the Atlantic species *aya* and *marcellae* to be the nearest relatives of their Eastern Pacific *falcifer*. Certainly *goniodes* should be included in this same group of species.

Named *goniodes* (Gr., *gonia* = angled) in reference to the acute angle formed by the ocular and body bars.

ACKNOWLEDGMENTS

I wish to thank Mr. Harvey Bullis, Director, Gulf and South Atlantic Exploration and Gear Research, Pascagoula, Mississippi, for inviting me to accompany OREGON Cruise 62 as an observer and permitting me to describe this species. I should also like to thank Dr. C. L. Hubbs, Scripps Institution of Oceanography, La Jolla, California, for suggestions and encouragement.

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THE CHAETOGNATHA OF THE NORTHEASTERN COAST OF HONDURAS, CENTRAL AMERICA¹

JOSÉ A. SUÁREZ-CAABRO AND JUAN E. MADRUGA

Marine Laboratory, University of Villanueva

Marianao, Cuba

ABSTRACT

A total of 2270 specimens of Chaetognatha were found in nine stations between the 100 fathom line and the coast. *Sagitta hispida*, *S. tenuis*, *S. enflata*, *S. serratodentata*, *Krohnitta pacifica*, *K. subtilis* and *Pterosagitta draco* were identified. The most common species among those collected is *Sagitta hispida* which was found at all stations.

INTRODUCTION

In July of 1951 the Cuban Government organized and carried out an exploration of fish population in the waters of the Caribbean Sea near the northeast coast of Honduras in Central America. This voyage had the purpose of obtaining information on new fishing grounds for the Havana fishing fleet, which customarily conducted its activities on the Campeche Bank, Mexico.

Coast Guard ship GC-106 of the Cuban Navy accompanied the Cuban fishing boats. Dr. Luis Howell Rivero, Chief of the Cuban Naval Hydrographic Office, had charge of the scientific work aboard the Coast Guard ship.

The material studied was supplied to Dr. Suárez-Caabro by Dr. Howell Rivero, whom we thank for his courtesy and generosity. The sketches were drawn by Mr. Warden F. Johnson who also translated the original Spanish manuscript to English.

AREA STUDIED

During the voyage nine stations were established about 15 miles north of Cape Gracias a Dios in an area that ran from one mile from the coast near Laguna Caratasca, with a depth of 12.8 meters, to almost 75 miles northeastward (15 miles north of Gorda Bank), where the depth was 45.7 meters (Figure 1 and Table 1). All stations were in the Caribbean Sea near the northeast coast of Honduras.

¹Monograph 8 from The Marine Laboratory, University of Villanueva.

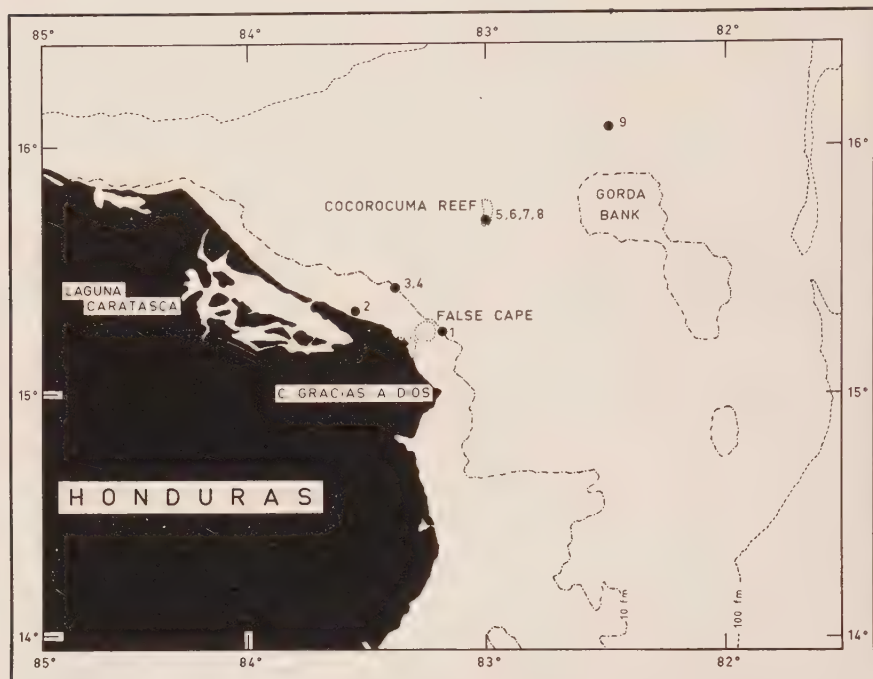


FIGURE 1. Collecting stations in the Caribbean Sea near the northeast coast of Honduras, Central America.

FIELD OPERATIONS

The specimens were obtained by means of surface tows, using a No. 20 plankton net of 0.30 meter diameter with 0.076 mm mesh. All specimens were preserved in dilute formalin.

TABLE 1
LOCATION OF STATIONS

Map Station	N. Lat.	W. Long.	Date (1951)	Time
1	15°15'	83°11'	July 2	0800-0830
2	15°21'	83°35'	July 2	1130-1200
3	15°25'	83°24'	July 2	2000-2030
4	15°25'	83°24'	July 3	0007-0037
5	15°43'	83°01'	July 3	1300-1330
6	15°43'	83°01'	July 3	1930-2000
7	15°43'	83°01'	July 3	2130-2200
8	15°43'	83°01'	July 3	2330-2400
9	16°05'	82°27'	July 4	2100-2130

LABORATORY PROCEDURES

All chaetognaths were separated from the plankton samples which contained them and placed in separate vials. Identification of species was made by following the same standards established by Suárez-Caabro (1955). In this study the relative character of the form of the ocular pigment was a detail which was frequently used to confirm the identification of the species, especially in *Sagitta hispida*, *S. enflata* and *S. tenuis* (Furnest, 1954 and 1957, and Tokioka, 1955). Poorly preserved, damaged, and very small specimens were removed, counted and examined only at higher magnifications.

Sagitta hispida Conant

(Figure 2A)

This is the most abundant species in the material studied. Although the specimens obtained were between 4 to 11 mm in length, the majority were from 7 to 8 mm long. They usually had 7 to 8 hooks. The anterior teeth generally varied between 5 to 10, but some specimens were found to have only 3 and 4.

Formula:

Number of Specimens	Length mm	Tail per cent	Hooks	Anterior teeth	Posterior teeth
13	4-5	26.7-33.4	6-9	3-6	6-10
88	5-6	27.3-35.3	5-10	4-8	4-11
279	6-7	27.1-32.9	6-10	5-10	6-13
348	7-8	26.3-34.7	5-9	6-9	9-13
48	8-9	28.9-32.9	6-9	6-10	9-13
3	9-11	28.5-30.0	7-8	8-9	8-12

Sagitta enflata Grassi

(Figure 2B)

The *Sagitta enflata* is less abundant than the *S. hispida*. The largest specimens reach a length of 16 mm and the smallest ones are 4 mm long. Their hooks number between 6 and 11. The anterior teeth vary from 3 to 9 while the posterior teeth number between 4 and 16.

Formula:

Number of Specimens	Length mm	Tail per cent	Hooks	Anterior teeth	Posterior teeth
11	4-7	17.2-26.7	9-11	3-6	4-7
52	7-10	16.7-26.3	6-11	4-8	8-13
45	10-12	17.0-21.0	8-11	5-8	8-16
6	12-16	14.0-20.8	8-10	6-9	11-13

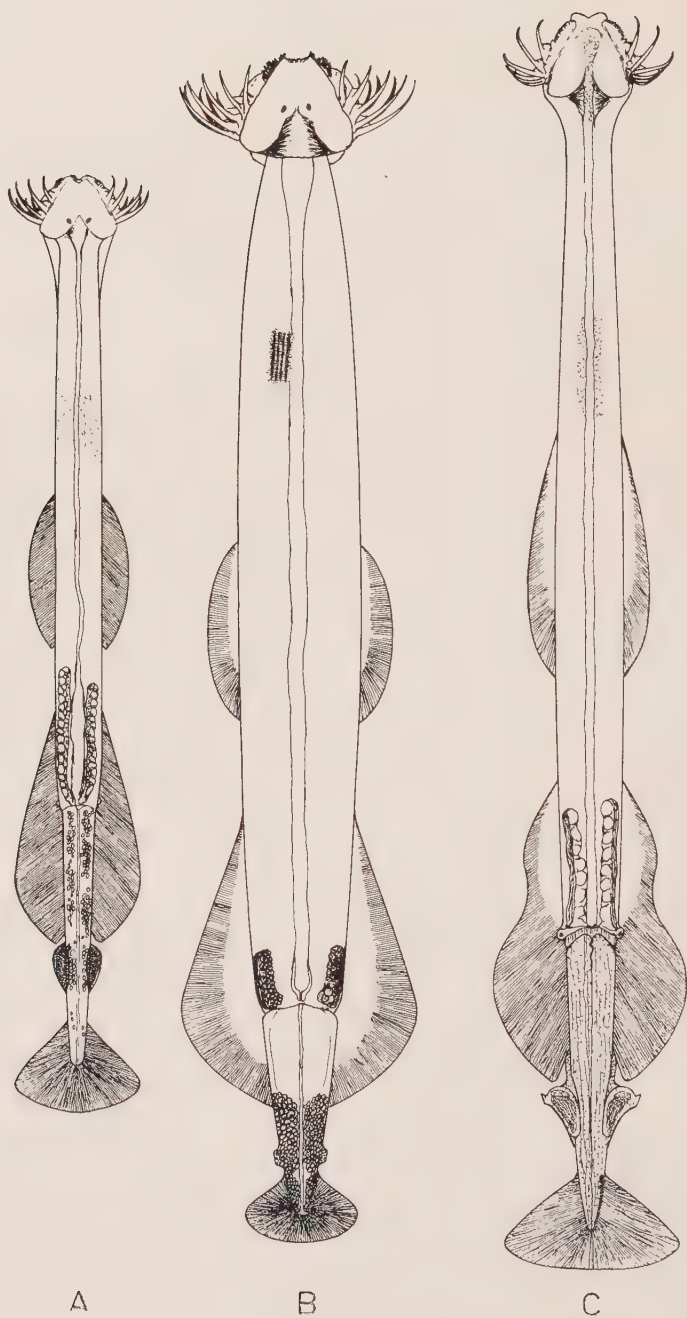


FIGURE 2. A—*Sagitta hispida* Conant. B—*Sagitta enflata* Grassi, C—*Sagitta serratodentata* Krohn.

Sagitta serratodentata Krohn

(Figure 2C)

Only two specimens of this species were found measuring 7.5 mm and 10.1 mm in length. They have 6 to 7 hooks, from 6 to 8 anterior teeth and 12 to 18 posterior teeth.

Formula:

Number of Specimens	Length mm	Tail per cent	Hooks	Anterior teeth	Posterior teeth
1	7.5	28.0	7.7	6-6	12-12
1	10.1	24.7	6-6	8-8	18-18

Sagitta tenuis Conant

(Figure 3A)

The largest of the seven specimens of this species measures 8 mm and the smallest 4 mm. The hooks vary from 6 to 8, the anterior teeth number from 4 to 7 and the posterior teeth number from 6 to 13.

Formula:

Number of Specimens	Length mm	Tail per cent	Hooks	Anterior teeth	Posterior teeth
4	4-5	27.5-28.5	6-8	4-5	6-8
3	7-8	26.7-27.7	7-8	4-7	10-13

Krohnitta subtilis Grassi

(Figure 3B)

A total of 16 specimens of this species were found. Their length varies between 4 and 6.5 mm. All specimens have from 7 to 8 hooks, and the number of teeth varies between 10 and 14. More than half of the 16 specimens exhibit developed seminal vesicles.

Formula:

Number of Specimens	Length mm	Tail per cent	Hooks	Teeth
9	4-5	33.3-37.5	7-8	10-14
7	5-6.5	32.7-33.3	7-8	12-13

Krohnitta pacifica Aida

(Figure 3C)

This species is less numerous than the *K. subtilis*. Only 9 specimens were found, which measure from 4 mm to 6 mm in length. The hooks vary in number from 7 to 10 and the teeth number between 11 and 13.

Formula:

Number of Specimens	Length mm	Tail per cent	Hooks	Teeth
5	4-5	29.1-36.0	7-10	11-13
4	5-6	31.1-36.3	7-8	12-13

Pterosagitta draco Krohn

(Figure 3D)

Only two specimens of this species were found, which measure 3.5 mm and 6.5 mm in length. They exhibit from 8 to 9 hooks, between 4 and 8 anterior teeth and from 8 to 12 posterior teeth. These specimens are in a rather bad state of preservation and the collarette, in both, is almost completely destroyed. Only one of the two has seminal vesicles.

Formula:

Number of Specimens	Length mm	Tail per cent	Hooks	Anterior teeth	Posterior teeth
1	3.5	42.8	8-8	4-4	8-8
1	6.5	43.2	9-9	8-8	12-12

OCCURRENCE OF CHAETOGNATHA

We know of no previous reports on the occurrence and distribution of chaetognaths in the area concerned. Nevertheless, all species collected and studied here were mentioned in one or another of the investigations which were carried out in other regions of the Caribbean Sea and the Gulf of Mexico by Conant (1895), Ritter-Zahony (1910), Pierce (1954), and Suárez-Caabro (1955).

Seven species of chaetognaths were collected between the 100 fathom (182.9 m) line and Laguna de Caratasca, Honduras (Table 2). They were *Sagitta hispida*, *S. tenuis*, *S. enflata*, *S. serratodentata*, *Krohnitta pacifica*, *K. subtilis* and *Pterosagitta draco*.

S. hispida and *S. enflata* are the most common species, being present at almost all the stations. The first is closely associated with shallow waters of low salinity (Pierce 1951) and the second is typically an offshore species, yet it appears in those stations which were closest to the coast. Possibly, this is due to its euryhaline character and to the fact that the area is a region of open sea. Note that *S. enflata* did not appear in Station 2, which is the nearest to the coast and where there was the least depth, corroborating the aforementioned criteria.

Continuing in the order of occurrence are *K. subtilis*, *K. pacifica* and *S. tenuis*. The first two were only found on Cocorocuma Reef (Figure 1) and *S. tenuis*, which was collected only at Station 2, is a species frequently appearing in waters very near the coast and being generally the most abundant chaetognath in semi-enclosed bodies of water (Pierce 1958).

S. serratodentata and *Pterosagitta draco* were collected exclusively

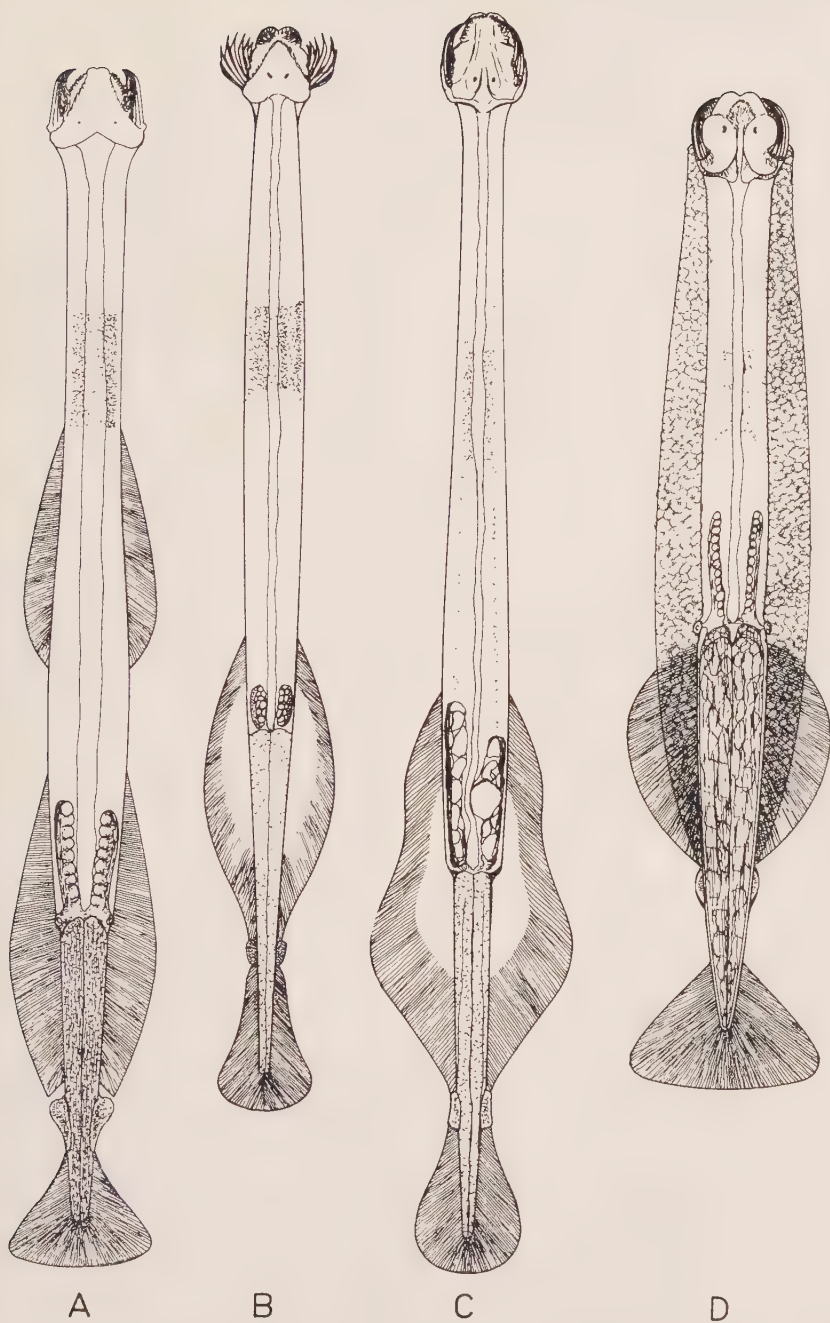


FIGURE 3. A—*Sagitta tenuis* Conant. B—*Krohnitta subtilis* Grassi. C—*Krohnitta pacifica* Aida. D—*Pterosagitta draco* Krohn.

at Station 9, which is the most typically oceanic of all the stations, since it is some 90 miles from the coast and has 45.7 m of depth.

ABUNDANCE

Since no quantitative sample of plankton was obtained the abundance of the chaetognaths studied can not be precisely determined. Nevertheless, we give some figures relative to the quantity of chaetognaths which appeared in the samples collected.

A sample was collected at each station and a total of 2,270 specimens were found of which 59 per cent were damaged, poorly preserved or were too small for positive identification (Table 2).

The greatest number of specimens was found in the samples taken inside the 10 fathom (18.3) line, corresponding to Station 1 to 4. In this zone 2,052 chaetognaths were collected, representing 90 per cent of the total collected. Among them, 59 per cent could not be identified for the reason given above. The remainder was made up of only three species: *S. hispida* (738), *S. enflata* (93) and *S. tenuis* (7).

At the stations occupied on Cocorocuma Reef and to the north of Gorda Bank, which were situated farthest from the coast and had depths of 29.3 m and 45.7 m respectively, few chaetognaths were found although in the samples obtained there, *S. serratodentata*, *K. pacifica*, *K. subtilis* and *P. draco* were found in addition to *S. hispida* and *S. enflata*.

TABLE 2
NUMBER OF CHAETOGNATHA (GENERA *Sagitta*, *Krohnitta* AND *Pterosagitta*)
BY STATIONS

Map station	Depth in meters	<i>S. hispida</i>	<i>S. tenuis</i>	<i>S. enflata</i>	<i>S. serratodentata</i>	<i>K. pacifica</i>	<i>K. subtilis</i>	<i>P. draco</i>	Damaged, poorly preserved or very small	Total
1	18.3	44	0	29	0	0	0	0	242	315
2	12.8	451	7	0	0	0	0	0	484	942
3	18.3	92	0	38	0	0	0	0	330	460
4	18.3	151	0	26	0	0	0	0	158	335
5	29.3	11	0	1	0	4	12	0	50	78
6	29.3	25	0	11	0	2	0	0	16	54
7	29.3	2	0	3	0	3	0	0	33	41
8	29.3	1	0	1	0	0	4	0	18	24
9	45.7	2	0	5	2	0	0	2	10	21
Totals		779	7	114	2	9	16	2	1341	2270

DISCUSSION

The most common species among those collected is *S. hispida*, which was found at all stations, but being more abundant at those near the coast and in shallow water areas. Suárez-Caabro (1955) found *S. hispida* under equal conditions in the waters of the north and south coasts of Cuba. This species was reported by Pierce (1951) as having equal habitat on the western coast of Florida. *S. enflata* also was found at the same stations as *S. hispida*, with the exception of Station 2; its number also diminished in proportion as the samples were taken farther from the shallow waters. Nevertheless, Suárez-Caabro (1955) points out that *S. enflata* was found in 90 per cent of the plankton samples obtained in oceanic waters to the north and south of Cuba. Possibly, the area studied, since it is an open region, is influenced by the water of the Caribbean current.

S. tenuis appeared only in Station 2 and in very small quantity. The remainder of the chaetognaths under study, *S. serratodentata*, *K. pacifica*, *K. subtilis* and *P. draco*, were found in deeper waters, from 29.3 m to greater depths.

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AN ANALYSIS OF THE RELATION OF THE VERTICAL DISTRIBUTION OF THREE COPEPODS TO ENVIRONMENTAL CONDITIONS¹

H. B. MOORE AND JOHN C. BAUER
The Marine Laboratory, University of Miami

ABSTRACT

The vertical distribution of three species of copepods has been determined from about 400 net hauls. This is analyzed in terms of temperature, illumination, pressure and a seasonal cycle probably associated with successive broods. Variations of behavior within the populations are demonstrated as well as diurnal rhythms in behavior.

INTRODUCTION

The vertical distribution of zooplankton can rarely be accounted for in terms of a single external condition such as illumination. It is becoming increasingly obvious that it is usually the resultant of a complex, not only of reactions to different factors, but also of varying responses to the same factor. Furthermore it seems probable that the behavior of zooplankton under laboratory conditions often departs considerably from that under natural conditions. Finally, although there appears to be a remarkably constant behavior pattern running through widely different groups of zooplankton, there are specific differences. These present dangers when the results of studies of the behavior of one or two selected forms are extrapolated to account for the distribution of the mixture of species constituting the natural plankton population.

Study of the deep scattering layer, which is undoubtedly of mixed and varying origin, suggested the value of a statistical study of the relations between the vertical distribution of zooplankton as it occurred under natural conditions and selected factors in the environment. A mathematical model has been developed which, although clearly oversimplified, has yielded values for depth distribution which agree well with those observed under rather widely varying conditions. In addition it has yielded a number of interesting generalizations with regard to plankton behavior (Moore *et al.*, 1953; Moore, 1955; Moore and Corwin, 1956). To obtain a more adequate array of raw data than was available in the earlier work, eleven 24 hour stations

¹Contribution No. 288 from The Marine Laboratory, University of Miami.

were worked under a grant from the National Science Foundation, and the copepods in the approximately four hundred net hauls were counted. The analysis of the results is being made under a contract from the Office of Naval Research, No. NONr 840 (12). Out of twenty species initially counted, sixteen were consistently present in sufficient numbers to be of use for analysis. An account of their general distribution has already been published (Moore and O'Berry, 1957) and this and the papers already referred to describe the methods of treating the data. The copepods fell into four groups. There were the deep-living ones with a very extensive diurnal migration, there were intermediate ones with a marked but less extensive migration, and there were shallow ones with either no migration or a reversed movement which took them upwards in the day time and down at night. A fourth group included only a single harpacticoid species which was aberrant in showing no diurnal migration although it lived at a considerable depth. We hope ultimately to analyze the data from all of these species and to compare their behavior factors, as determined in the mathematical model, with their observed differences in vertical and geographical distribution. The present paper contains the results of analysis of three deep-living species. *Rhincalanus cornutus* Dana has a mean day level (above which 30 per cent of the population occur) at the 40-mile station of 392 meters and a mean diurnal range of 147 meters (Moore and O'Berry, 1957). *Pleuromamma abdominalis* Lubbock was slightly shallower, with a mean day level of 348 meters and a diurnal range of 186 meters. *P. gracilis* Lubbock had a mean day level of 335 meters and a diurnal range of 213 meters, the greatest of the three. In the Bermuda area (Moore, 1949) the mean day level for *P. abdominalis* was 450 meters, and that for *P. gracilis* 300 meters.

In an earlier analysis of four species of siphonophores (Moore and Corwin, 1956), the assumption was made that there are three significant controlling factors, temperature, illumination and pressure. For each of these there is a nul value (T_n , I_n , P_n) at which there is no stimulus for the animal to move vertically. It was further assumed for the sake of simplicity that stimulus to vertical movement was linearly proportional to the difference between these nul values and the current external conditions ($T-T_n$, $I-I_n$, $P-P_n$). Temperature is measured in °C, illumination as the exponent to the base 10, with full overhead sunlight equaling +2, and pressure in meters of water. Response by vertical movement will depend on the nature of the stimulus and on

the units in which it is measured, so the above stimuli must be multiplied by appropriate factors (T. Fac., I. Fac., P. Fac.) to represent equal reactions to unit stimulus. A positive reaction is designated as representing a tendency to move deeper and a negative reaction as a tendency to move shallower. If an animal is in equilibrium with external conditions—and it is assumed that it can move fast enough to keep pace with changing conditions—then the sum of its reactions should equal zero, and an equation may be written in the form:

$$\text{T. Fac. (T-T}_n\text{)} + \text{I. Fac. (I-I}_n\text{)} + \text{P. Fac. (P-P}_n\text{)} = 0.$$

Since the three factors are only relative, one of them, namely pressure, is assumed to equal unity and so may be omitted from the equation. The equation must be solved in two stages, the first yielding the factors and the second stage the nul values. The present paper is concerned only with the values of the factors.

Since behavior was found to vary at different levels in a population of a given species, separate analyses are made at each ten per cent of the population. The 30 per cent level thus represents that level in the population above which 30 per cent of the animals are found. There are diurnal changes also in behavior, so separate analyses are made every four hours. Unfortunately there were insufficient data for 04.00 hours, so this has had to be omitted throughout.

In an analysis of earlier material, group comparisons were made between pteropods, siphonophores, chaetognaths and copepods (Moore *et al.*, 1953). After accounting for the differences in level due to temperature and illumination, the copepods showed a residual seasonal movement which, it was suggested, might be due to behavior differences in successive broods. The other three groups did not show this effect. The possibility of studying this was one reason for selecting the copepods in the present work.

METHODS

The only change in methods from that used for the siphonophore analyses (Moore and Corwin, 1956) was the inclusion of a term for brood effect. The dates on which the hauls were made were expressed as the number of days from the first of January and then successively from the first of February, March, April, May and June. Using each of these six base dates in succession, but taking only the 30 to 60 per cent levels to save time, date factors were calculated in the same way as, and at the same time as the temperature and illumination factors.

the necessary term being simply added in the partial regression analysis. The month yielding the highest date factor was selected, and, if this had a positive date factor, this month was assumed to represent the highest point on the seasonal cycle. If the greatest value had a negative value, this was taken to represent the deepest part of the cycle, with the highest part six months later. Taking this as the base date, the factors were then calculated for the remaining percentage levels. A similar process was carried out at four hour intervals throughout 24 hours.

The equilibrium equation, with the date term included, now became:
 $T. \text{ Fac. } (T - T_n) + I. \text{ Fac. } (I - I_n) + P. \text{ Fac. } (P - P_n) + \text{Date Fac. Date} = 0$

RESULTS

Temperature factor. Analysis of the vertical distribution of four species of siphonophores (Moore and Corwin, 1956) yielded mean values of the temperature factor through the 24 hours of +20.7, +17.3, +23.6 and +24.9. Similar means for the three copepod species are *P. gracilis* +5.16, *P. abdominalis* +3.40 and *R. cornutus* +2.81. A date factor was not used in the siphonophore analyses since no significant correlation has been found between date and depth. The lower temperature factor in the copepods results from the introduction of a date factor and the extent of its reduction is probably due to association with a temperature cycle, as will be discussed later.

The general trend in all three copepods is for the upper members of the population to have a strong positive temperature factor which decreases downward through the population, often attaining a negative value in the lower levels (Fig. 1). Considerable smoothing has been employed to avoid unnecessary complication in these figures, but the original values are given in Table 1. This smoothing has been based on the assumption that the typical curve is a sigmoid resulting from the accumulation of a skewed normal population—10, 80 and 90 per cent levels—are drawn from smaller and less adequate counts than the central region of the population. There is also, in all three species, a marked diurnal rhythm, with a low or negative temperature factor at noon, and a maximum value at 20.00 or at midnight. This rhythm differs somewhat from that found in the four siphonophores. These showed a similar noon minimum, but their maximum was earlier, at

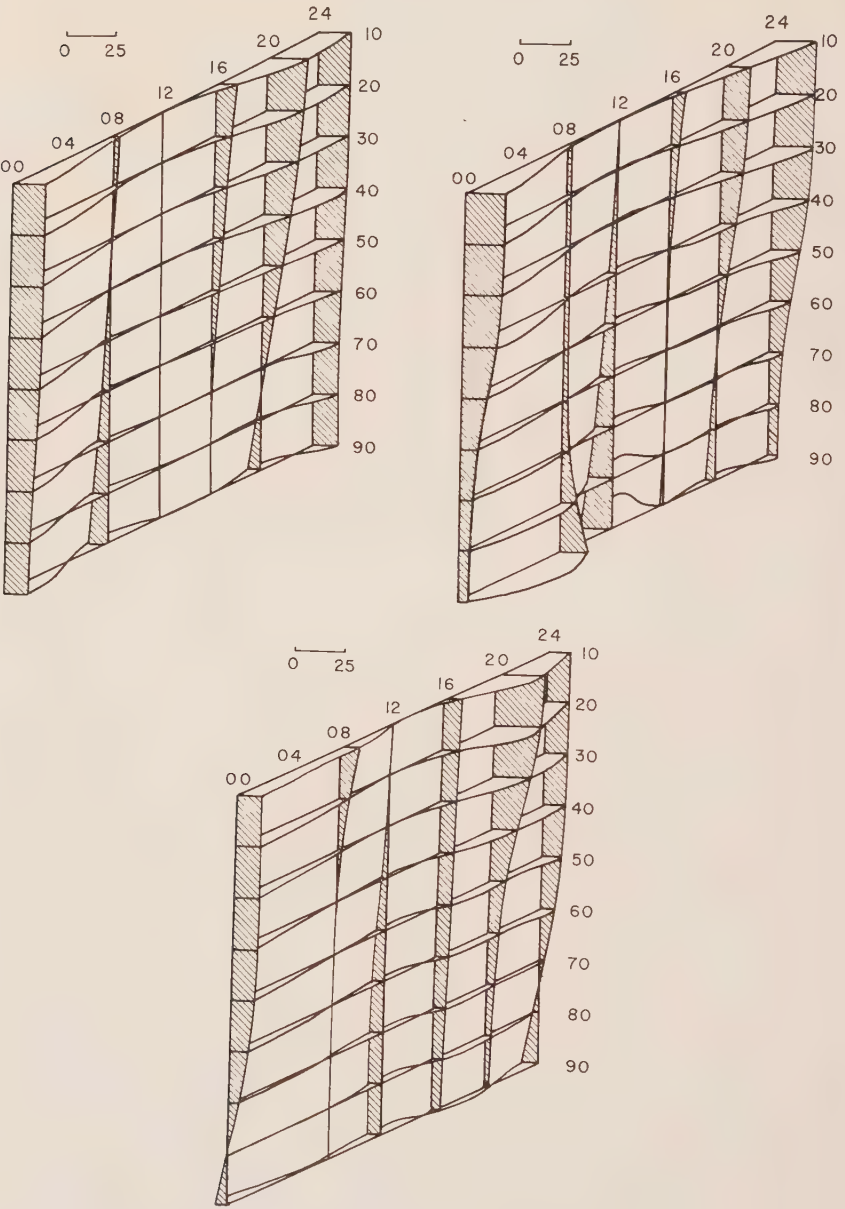


FIGURE 1. Relation of temperature factor to time of day (oblique) and percentage level (vertical). *Pleuromamma gracilis* (left), *P. abdominalis* (center), *Rhincalanus cornutus* (right).

TABLE I
Pleuromamma abdominalis

% level	Time	Temperature factor				
		00.00	08.00	12.00	16.00	20.00
10		+ 12.40	+ 6.45	+ 0.44	+ 6.18	+ 12.05
20		+ 14.81	+ 2.43	— 3.80	+ 4.64	+ 15.29
30		+ 21.33	+ 2.28	+ 5.39	+ 4.09	+ 11.22
40		+ 19.04	— 0.25	— 6.22	+ 2.40	+ 20.17
50		+ 14.05	+ 1.25	— 6.39	+ 2.29	+ 6.52
60		+ 9.07	— 2.65	— 8.08	— 1.70	— 0.33
70		+ 5.79	+ 3.64	— 8.70	— 1.15	— 1.94
80		+ 5.64	+ 4.83	— 10.64	— 2.11	— 3.30
90		+ 5.07	+ 13.39	— 19.13	+ 2.62	— 5.06
Illumination Factor						
10		+ 17.23	+ 26.67	+ 35.00	+ 21.67	+ 11.89
20		+ 16.54	+ 29.44	+ 37.89	+ 20.78	+ 14.59
30		+ 16.68	+ 29.55	+ 32.01	+ 21.38	+ 15.65
40		+ 21.43	+ 29.99	+ 37.00	+ 20.97	+ 15.22
50		+ 25.00	+ 27.98	+ 36.49	+ 21.19	+ 18.71
60		+ 26.46	+ 29.41	+ 35.37	+ 20.83	+ 18.85
70		+ 25.50	+ 29.86	+ 35.31	+ 22.83	+ 19.45
80		+ 23.76	+ 28.09	+ 36.15	+ 23.17	+ 19.72
90		+ 21.74	+ 38.40	+ 34.92	+ 22.02	+ 20.56
Date Factor						
	Month	Dec.	Mar.	Mar.	Feb.	Sep.
10		— 0.29	— 0.45	— 0.37	— 0.13	— 0.29
20		— 0.39	— 0.57	— 0.75	— 0.12	— 0.19
30		— 0.45	— 0.67	— 0.37	— 0.10	— 0.38
40		— 0.43	— 0.84	— 0.92	— 0.11	— 0.32
50		— 0.59	— 0.85	— 0.94	— 0.14	— 0.34
60		— 0.57	— 1.06	— 0.90	— 0.43	— 0.25
70		— 0.70	— 0.82	— 0.92	— 0.50	— 0.22
80		— 0.92	— 0.66	— 1.03	— 0.58	— 0.19
90		— 1.21	— 0.69	— 1.49	— 0.27	— 0.16

1600 to 20.00 hr. The siphonophores also differed from these copepods in that the temperature factor in general increased downwards through the population.

Illumination factor. The means for 24 hours were *P. gracilis* + 25.03, *P. abdominalis* + 25.18 and *R. cornutus* + 31.14. These values are a little higher than those found in the four siphonophores whose mean value was 20.27. Except at noon, when it was very constant, the illumination factors showed a slight general increase downward through the population, when a mean for all three species for the 24

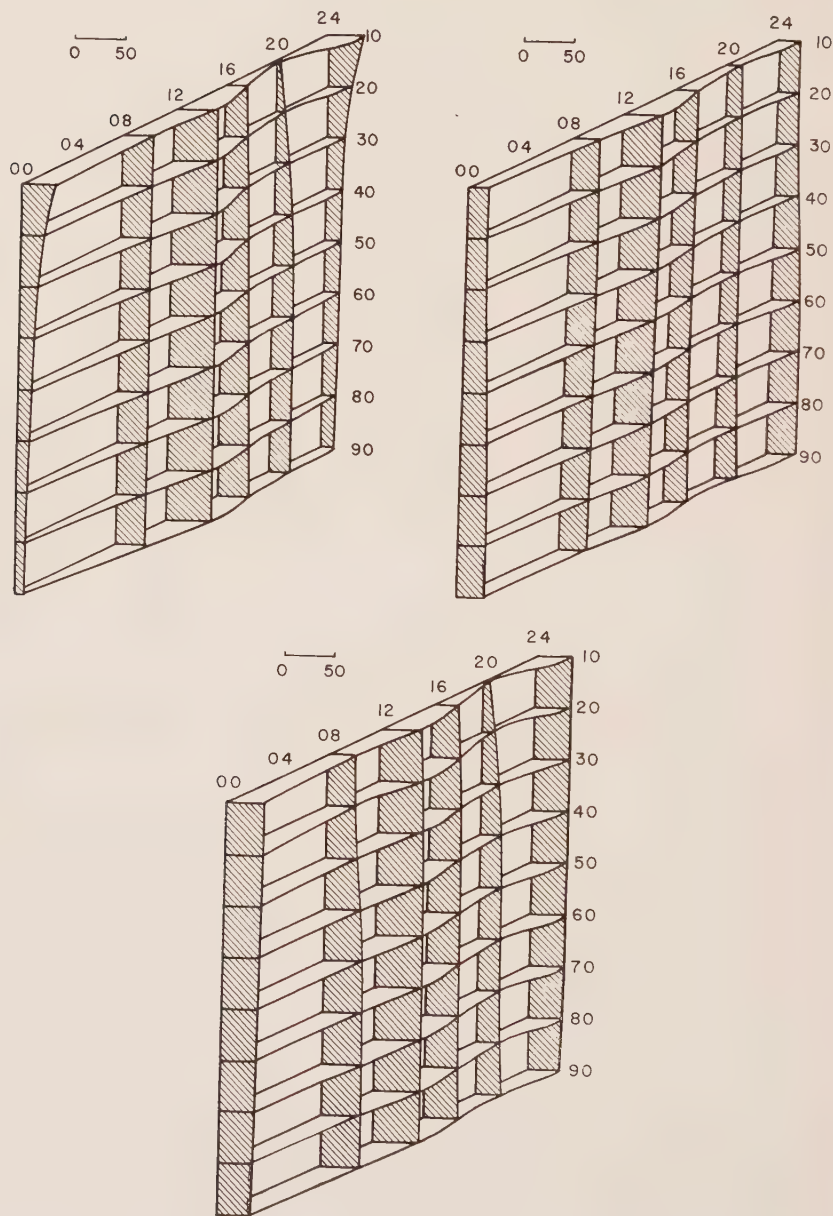


FIGURE 2. Relation of illumination factor to time of day (oblique) and percentage level (vertical). *Pleuromamma gracilis* (left), *P. abdominalis* (center), *Rhincalanus cornutus* (right).

TABLE II
Pleuromamma gracilis

% level	Time	Temperature Factor				
		00.00	08.00	12.00	16.00	20.00
10		+20.90	+ 3.00	— 0.28	+ 9.85	+19.81
20		+ 9.51	+ 0.37	— 2.34	+ 8.39	+17.33
30		+13.05	+ 0.14	— 0.61	+ 6.01	+19.51
40		+13.83	+ 4.29	— 1.54	+ 5.53	+26.41
50		+14.52	— 6.69	— 2.70	+ 4.33	+ 6.34
60		+16.05	— 7.49	— 2.85	+ 1.65	+ 2.92
70		+10.29	+ 8.38	+ 2.70	— 1.26	— 0.18
80		+ 8.65	— 8.27	+ 5.02	+ 0.54	— 6.55
90		+10.33	+11.52	— 8.13	+10.18	—10.00
Illumination Factor						
10		+35.52	+28.96	+39.11	+18.98	+ 3.97
20		+12.73	+29.49	+41.24	+20.29	+10.84
30		+15.92	+29.70	+41.20	+21.52	+20.62
40		+16.23	+28.49	+45.52	+22.74	+24.14
50		+15.64	+28.54	+44.62	+22.31	+17.84
60		+11.80	+28.99	+45.28	+20.02	+16.96
70		+12.23	+29.26	+39.46	+18.45	+16.91
80		+ 8.89	+24.48	+43.07	+21.11	+16.64
90		+14.20	+34.72	+40.41	+30.51	+17.19
Date Factor						
	Month	Oct.	Feb.	Mar.	Nov.	Oct.
10		— 0.09	— 0.51	— 0.44	— 0.36	— 0.17
20		— 0.27	— 0.64	— 0.73	— 0.34	— 0.62
30		— 0.55	— 0.80	— 0.76	— 0.08	— 1.22
40		— 0.65	— 1.13	— 1.04	+ 0.19	— 1.74
50		— 0.77	— 1.41	— 1.13	— 0.00	— 0.50
60		— 1.18	— 1.51	— 1.21	— 0.10	— 0.45
70		— 1.22	— 1.60	— 0.37	— 0.13	— 0.35
80		— 1.46	— 1.54	— 0.42	— 0.16	— 0.14
90		— 1.31	+ 0.02	— 1.45	— 0.01	— 0.09

hours was considered. The only downward decrease was in *P. gracilis* in the midnight series. A similar constant noon value was found in the siphonophores, but with a downward increase in only two of the series, and a downward decrease in the other two.

The diurnal rhythm is marked and follows closely that found in the siphonophores. The mean values for the three species, taking all percentage levels together were:

Time	00.00	08.00	12.00	16.00	20.00
I. factor	+23.16	+30.99	+40.60	+24.43	+26.42

Date factor. The date factor shows a marked increase downwards in all three species, and, at least in the lower levels, a strong diurnal rhythm with a minimum at 16.00 or 20.00. The three species were consistent in having the low point of the cycle in March so far as their noon levels were concerned. There was a diurnal rhythm in these dates with the night values occurring earlier in the winter. The earliest dates correspond with the 20.00 samples in all species. At midnight *P. gracilis* showed the same date, but *P. abdominalis* has dropped back halfway to the midday date and *R. cornutus* had dropped to a month later than the midday date. All three thus showed a similar diurnal shift, but with some difference in the timing of the shift between the three species.

DISCUSSION

As has already been emphasized earlier in this work, the results obtained should be considered significant only in their broad trends and not in fine detail. Further, consideration of a number of species will be necessary before a generally valid picture can be obtained.

In an earlier study (Moore *et al.*, 1953) in which data for eighteen species of copepods were combined, a positive regression was found of vertical movements of the day level of the copepods on those of the 15° C isotherm. These regressions were stronger in the lower parts of the population. Similar results were found in groups of pteropods, siphonophores and chaetognaths. In the case of the copepods, though, significant results were obtained only when the partial regressions were calculated so as to eliminate a seasonal factor as well as illumination. These regressions were on the movement of an isotherm and not directly on temperature. A study of four species of siphonophores (Moore and Corwin, 1956), carried out throughout the 24 hours, showed a similar increase in temperature regression downwards through the population, and here the regressions were made on temperature directly in the form of the present temperature factor. In the three species of copepods studied here the temperature factors consistently decreases downward through the population. The introduction of a date factor has reduced the magnitude of the temperature factor, but has not resulted in any change of trend. This direction of trend is probably a characteristic of deep-living species. More species will have to be analyzed, but preliminary results suggest that the pattern found in the shallower-living siphonophores is found also in some shallower copepods.

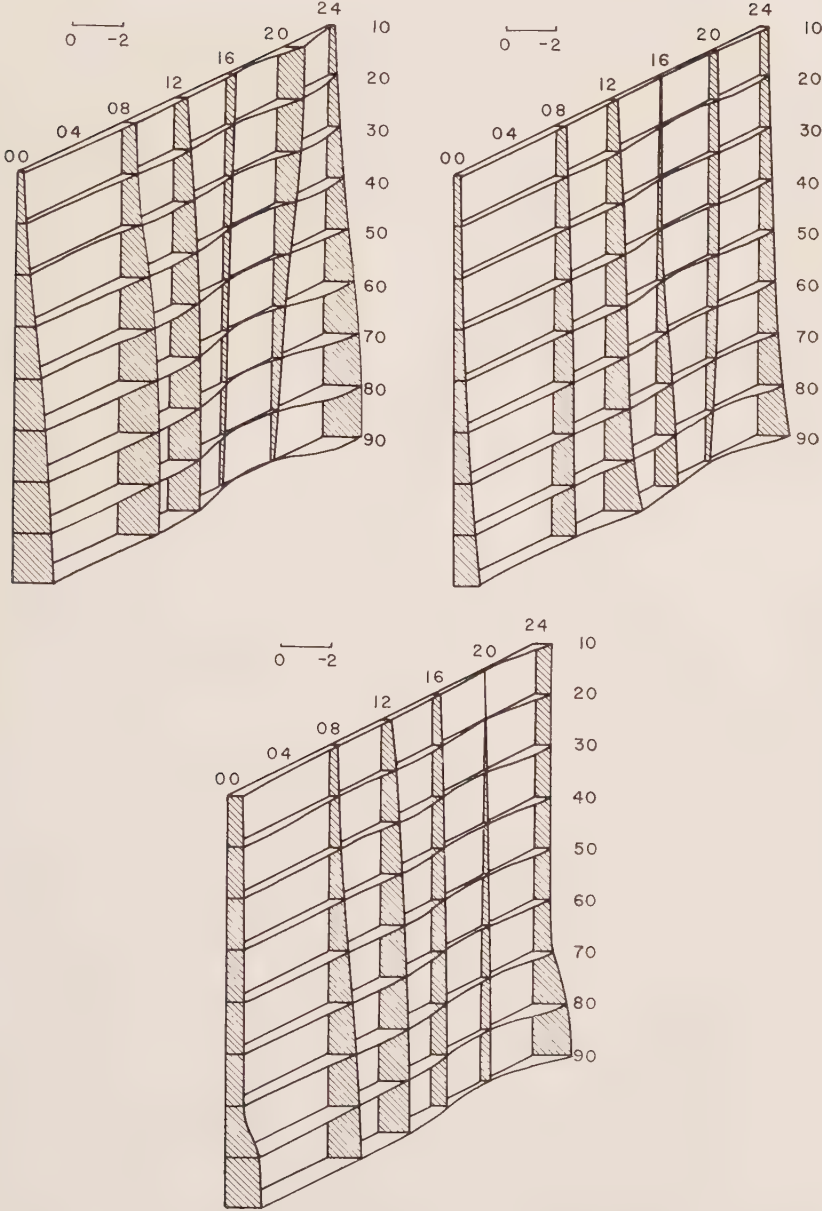


FIGURE 3. Relation of date factor to time of day (oblique) and percentage level (vertical). *Pleuromamma gracilis* (left), *P. abdominalis* (center), *Rhincalanus cornutus* (right).

TABLE III
Rhincalanus cornutus

% level	Time	Temperature Factor				
		00.00	08.00	12.00	16.00	20.00
10		-18.57	+ 9.95	+ 0.14	+ 7.67	+21.52
20		+13.66	+ 6.12	- 0.35	+ 6.28	+24.43
30		+ 9.86	+ 2.58	- 1.47	+ 7.10	+15.28
40		+ 7.31	+ 0.63	- 2.56	+ 6.25	+13.28
50		+ 8.10	+ 0.49	- 3.82	+ 6.69	+ 6.76
60		+ 7.44	- 1.40	- 7.45	+ 6.62	- 5.02
70		+ 8.00	- 0.76	- 5.14	+ 3.74	- 4.80
80		- 5.17	- 0.33	- 5.10	+ 2.98	- 2.24
90		- 7.19	- 1.72	- 4.99	+ 4.63	- 2.87
% level	Month	Illumination Factor				
		Apl.	May	May	Feb.	Nov.
10		+36.02	+27.39	+38.48	+24.35	+ 4.71
20		+29.02	+24.07	+43.00	+29.62	+ 6.05
30		+33.47	+30.32	+45.30	+28.28	+14.92
40		+33.82	+36.34	+45.95	+30.11	+16.70
50		+32.62	+37.33	+45.82	+30.01	+20.18
60		+31.33	+37.21	+46.38	+31.01	+20.57
70		+31.19	+37.38	+44.27	+31.72	+19.49
80		+30.60	+38.02	+43.98	+31.40	+20.56
90		+29.81	+36.83	+43.04	+31.51	+20.22
% level	Month	Date factor				
		Apl.	May	May	Feb.	Nov.
10		- 0.45	- 0.42	- 0.36	- 0.22	+ 0.01
20		- 0.59	- 0.01	- 0.66	- 0.46	+ 0.04
30		- 0.79	- 0.48	- 0.81	- 0.49	- 0.19
40		- 0.72	- 0.76	- 0.93	- 0.52	- 0.33
50		- 0.49	- 0.91	- 1.03	- 0.51	- 0.40
60		- 0.49	- 1.11	- 1.24	- 0.51	- 0.11
70		- 0.51	- 1.21	- 1.23	- 0.60	- 0.19
80		- 1.45	- 1.35	- 1.29	- 0.67	- 0.30
90		- 1.60	- 1.45	- 1.33	- 0.74	- 0.33

The reduction in the magnitude of the temperature factor when the date factor was introduced indicates a smaller dependence on local or temporary temperature fluctuations than had previously been believed. However, such dependence is still significant. Further, as discussed below, the date factor itself shows a similarity to seasonal temperature cycles which may indicate that a part of the temperature response is in the form of a "clock" rather than a direct response mechanism.

The diurnal rhythm in the temperature factor is similar to that

previously in siphonophores, but with some difference in timing. Both show a daytime minimum and a night maximum. This rhythm in response to unit temperature change appears to be real and not a result of suppression of the temperature response in a bright light. If the latter were the case either the temperature response should be suppressed in the upper levels at night, which is not the case, or else, if the light then is not sufficiently strong to produce suppression, the deep day levels, where a similar light intensity occurs, should not produce suppression. The reduction in temperature factor at deep day levels is just as strong as in the shallower levels.

The illumination factor is very similar in the copepods and in the siphonophores. The earlier group comparisons gave illumination values which were generally below the acceptable level of significance. The magnitude of the illumination factor is slightly higher in the copepods than in the siphonophores, and the diurnal rhythm is very similar. There is some difference, however, in the trend downwards through the population. In the copepods this was generally an increase in the factor, whereas in the siphonophores it varies more with time of day and showed an increased downwards only at midnight.

The date factor has proved particularly interesting, but will require analysis in further species for better understanding. To begin with it showed a marked increase downwards at most times of day. It showed also a marked diurnal rhythm with a minimum at either 16.00 or 20.00 and either rather uniform values for the rest of the 24 hours or a maximum at noon. In addition, the timing of the seasonal cycle, that is to say the months in which it attained its deepest and shallowest values, varied diurnally. In all three species it was at its shallowest in September so far as noon levels were concerned. At 20.00 hours the three species are at their shallowest in March, April and June respectively, while *R. cornutus* has shifted to October. The values for the latter species are perhaps atypical since *Rhincalanus* showed a much less consistent diurnal migration than the two *Pleuromamma* species. More species must be analyzed before it will be clear what comprises typical behavior, but it is clear that these three species show a seasonal change in level over and above that which can be accounted for by changes in temperature and illumination, and further that the seasonal timing of this rhythm varies with the time of day. The existence of such a seasonal rhythm was previously demonstrated for noon levels in the group analysis of eighteen copepod species (Moore *et al.*, 1953)

with the animals at their shallowest sometime between July and November.

Iselin (1936) has published a graph showing the seasonal temperature changes at different depths in typical Sargasso Sea water. He shows clearly the time lag involved in the downward transfer of surface temperature conditions and states that . . . "while it took about four months for the winter surface minimum to penetrate down to 300 meters, the summer maximum did not reach the same depth until after six months." Similar conditions are indicated for the 40 mile station off Miami, although the seasonal series is at present less complete than Iselin's. While, as previously stated, more species will have to be examined before definite conclusions can be drawn, it is interesting to consider the changes in the date factor in relation to the changes in temperature cycle with depth. The date factor represents a response not correlated with local or seasonal changes in the external conditions of temperature, illumination or pressure. It may, however, be an internal "clock" mechanism for depth control which has been associated in its origin with seasonal changes in one of these factors. Pressure seems improbable, and illumination can hardly be concerned since, if it were, a seasonal rhythm in the factor would hardly be expected at night. On the other hand there is a marked similarity to the seasonal temperature cycle. In particular, the copepods are near the surface at night and much deeper in the daytime. The surface and deep waters have differently timed temperature cycles. If the copepods have established a rhythm related to the seasonal temperature cycle it might be expected to show a different timing for the night levels and the day levels, and such is the case. If this tentative interpretation is correct it may be expected that future analysis of the behavior of shallower species will show a reduced seasonal shift in the date pattern or even, in those with a reversed diurnal migration, a reversal of the pattern. Finally, the values for the temperature factors calculated when a date factor is included in the equation are considerably smaller than those obtained when the date factor is excluded. This strongly suggests that in the copepods, in contrast with the chaetognaths, pteropods and siphonophores, the adjustment of the depth of the animals to prevailing temperature conditions has been to a considerable extent replaced by an inherent rhythm paralleling the seasonal temperature rhythms typical of the depths at which they normally live. Such a distinction might

well not be apparent except in a locality which had the rather extreme temperature contrasts exhibited in a transect of the Florida Current.

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EXAMPLES OF MIMICRY AND PROTECTIVE RESEMBLANCE IN TROPICAL MARINE FISHES¹

JOHN E. RANDALL AND HELEN A. RANDALL
The Marine Laboratory, University of Miami

ABSTRACT

Definitions of the terms mimicry and protective resemblance are given, and known examples of mimicry in fishes are discussed.

Further observations were made on the mimicry of the wrasse, *Thalassoma bifasciatum*, by the blenny, *Hemimblemaria simulus* in Florida.

A strong case is made for the mimicry of the wrasse *Labroides dimidiatus* by the blenny *Aspidontus taeniatus*, based on observations of these fishes in the Society Islands. *L. dimidiatus* feeds primarily on crustacean ectoparasites of other fishes, including predaceous species. *A. taeniatus* closely resembles *dimidiatus*, swims with its pectoral fins like a wrasse, and feeds in part by tearing pieces from the fins of other fishes.

The striking similarity of the young of the surgeonfish *Acanthurus pyroferus* to the gaudily colored angelfish *Centropyge flavissimus* would seem best explained in terms of mimicry; however, a biological basis remains to be found.

The resemblance of the serranid fish *Hypoplectrus gemma* to the damselfish *Chromis cyanea* in Florida is discussed as a possible case of mimicry. Mention is made of the superficial resemblance of other species of *Hypoplectrus* to damselfishes and surgeonfishes in the Virgin Islands.

The following examples of protective resemblance involving juvenile fishes are presented.

<i>Species</i>	<i>Family</i>	<i>Object Resembled</i>	<i>Locality</i>
<i>Novaculichthys taeniourus</i>	Labridae	Floating green or blue-green algae	Society Islands
<i>Hemipteronotus pentadactylus</i>	Labridae	Land plant debris	Society Islands
<i>Hemipteronotus pavo</i>	Labridae	Leaf	Society Islands
<i>Platax orbicularis</i>	Ephippidae	Leaf	Society Islands
<i>Trachinotus falcatus</i>	Carangidae	Floating leaf	Virgin Islands
<i>Gymnachirus williamsoni</i>	Soleidae	Sunken leaf	Virgin Islands
<i>Strongylura timicu</i>	Belonidae	Floating pieces of <i>Cymodocea</i>	Virgin Islands
<i>Strongylura</i> sp.	Belonidae	Twigs	Hawaiian Islands
<i>Sphyaena barracuda</i>	Sphyaenidae	Twigs	Society Islands West Indies
<i>Kyphosus sectatrix</i>	Kyphosidae	Floating <i>Sargassum</i>	Haiti
<i>Antennarius pauciradiatus</i>	Antennariidae	Dead <i>Udotea</i>	Virgin Islands
<i>Monacanthus setifer</i> and <i>Monacanthus ciliatus</i>	Monacanthidae	Benthic algae	Jamaica and Virgin Islands
<i>Paraclinus marmoratus</i>	Clinidae	Gorgonian	Florida
<i>Mugil vaigiensis</i>	Mugilidae	Bubbles	Society Islands
Group of goatfish	Mullidae	Benthic algae	Hawaiian Islands

¹Contribution No. 289 from The Marine Laboratory, University of Miami.

INTRODUCTION

There has been some confusion in the use of the terms protective resemblance and mimicry. Poulton (1898) defined them as follows: "In the former an animal resembles some object which is of no interest to its enemy, and in so doing is concealed; in the latter an animal resembles an object which is well known and avoided by its enemy, and in so doing becomes conspicuous." These definitions are followed in the present paper with one alteration, necessitated by consideration of the mimetic relationship between *Labroides dimidiatus* (Valenciennes, in C. and V.) and *Aspidontus taeniatus* Quoy and Gaimard which is discussed in detail below. Far from being avoided, the model, *L. dimidiatus*, is sought by fishes because of its habit of removing ectoparasites from them. In mimicry, therefore, an animal resembles an object which is well known and is avoided or not preyed upon by its enemy, and in so doing becomes conspicuous. In addition to the avoidance of enemies, mimicry and protective resemblance may be advantageous to predaceous species in obtaining food.

Examples of protective resemblance in fishes are legion. Many fishes which rest upon the bottom have the ability to blend with the background in color, and some such as the scorpaenids, lophiids, and antennariids possess structural modifications which augment their concealment. Breder (1946) has prepared a review of fishes which bear resemblance to plant parts, and Atz (1951) has written a recent popular account of this subject. Mimicry, on the other hand, is rare in fishes, as it is in other vertebrates.

The mere resemblance of one fish to another does not necessarily mean that mimicry is involved. Longley (1917: 279) wrote that much that has masqueraded as mimicry is nothing but the result of convergent evolution.

Tortonese (1956) noted the similarity in caudal coloration of the surgeonfish *Acanthurus xanthopterus* Valenciennes in C. and V. and the triggerfish *Sufflamen albicaudatus* (Rüppell) in the Red Sea. He stated that this might represent an example of mimicry, but he believes it more likely that the similarity is the result of the close phylogenetic relationship between the Acanthuridae and Balistidae.

Evidence for mimicry should follow other lines in addition to the similarity of two species in form and color. A mimic occupies the same habitat as the model, and its distribution frequently coincides with that of the model. The mimic may demonstrate some alteration of

behavior from that characteristic of the group to which it belongs which enhances its resemblance to the model. In Batesian mimicry the model is often common and the mimic relatively scarce. Most important, there should be some survival value to the mimic in its pose of the model.

Perhaps the best known case of mimicry in fishes is the similarity of the black-marked pectoral fin of the common sole, *Solea vulgaris* Quensel (= *S. solea* Linnaeus), to the black dorsal fins of the venomous weever fishes, *Trachinus draco* Linnaeus and *T. vipera* Cuvier in C. and V. (Masterman, 1908). When alarmed, the sole raises its pectoral fin in a menacing manner, suggestive of the erected dorsal fin of the weever when it is molested. The pectoral fins of other soles are not marked with black and are not elevated when the fishes are in danger. The distributions of the common sole and the weevers are nearly identical. Young soles live inshore in sandy bays with *T. vipera* and adults in deeper water on sand bottom with *T. draco*.

Another well known example concerns the sea snake, *Platurus colubrinus* Schneider, and a snake eel, *Myrichthys colubrinus* (Boddaert). Both forms are banded, and according to Schnee (1905) the ophichthiid may be mimicking the sea snake because of the poisonous bite of the latter. Mortensen (1922: 59) observed the eel and sea snake in muddy areas in Ambon, East Indies. He stated that the eel resembles the snake ". . . so completely in colour and shape that even an expert ichthyologist would hardly venture to say, except on a closer inspection, whether it is the fish or the snake he has before him."

A unique case of mimicry in fishes was described among cichlid fishes in Lake Nyasa, Africa, by Trewavas (1947). *Corematodus shiranus* Boulenger has a pattern of vertical or near vertical black bars, exactly similar to that of females and non-breeding males of Nyasa species of *Tilapia* of the *T. squamipinnis* group. The gut contents of six specimens of *C. shiranus* consisted entirely of minute scales like those of many cichlid fishes in the lake, including *T. squamipinnis*. Presumably, *C. shiranus* is able by its strong superficial resemblance to *T. squamipinnis* to school unnoticed with it and feed by rasping scales from its caudal fin. The numerous pointed teeth of *shiranus* are arranged in a broad file-like band.

An earlier example from freshwater was presented by Moenkhaus (1895). *Cottus richardsoni* (= *Cottus bairdi* Girard), the miller's

thumb or mottled sculpin, has a color pattern of four broad bars that extend downward and forward on the body. "The miller's thumb is a very horny, spiny and uninviting fish for food to any enemy that may live on small fish." Living with it in American streams are two darters, *Etheostoma blennioides* Gilbert and Swain and *Percina uranidea* (Jordan and Gilbert), and the young of the black sucker (or northern hog sucker), *Hypentelium nigricans* (LeSueur), all with a similar color pattern. Moenkhaus suggested that these fishes, which belong to families readily accepted as food, are mimics of the cottid and thereby enjoy reduced predation. Robins and Deubler (1955: Table 1), however, showed that nearly 50 per cent of the stomach contents of the burbot, *Lota lota lacustris* (Walbaum), consisted of *Cottus bairdi*. Furthermore, Robins has informed the authors that this cottid tends to enter small creeks whereas the three so-called mimics are in larger streams for the most part. The geographical distributions of all these species are far from the same. Although some doubt is cast upon the validity of Moenkhaus' claim for mimicry in this example, the concept that spiny fishes are preyed upon less than non-spiny forms, other factors being equal, is probably true. Hoogland, Morris, and Tinbergen (1956) showed that the sticklebacks, especially *Gasterosteus aculeatus* Linnaeus, are not eaten by perch (*Perca fluviatilis* Linnaeus) and pike (*Esox lucius* Linnaeus) with the frequency with which non-spiny freshwater fishes (*Phoxinus* [= *Chrosomus*], *Rutilus*, *Scardinius*, and *Carassius*) are taken. Tests with de-spined sticklebacks showed that the protection was mainly due to spines.

Whitley (1935: 346-348, Fig. 1) described a case of mimicry involving spines of fishes from North Queensland, Australia. The serranid fish *Centrogenys vaigiensis* (Quoy and Gaimard) bears a resemblance to the scorpaenid *Sebastapistes bynoensis laotale* Jordan and Seale. The scorpionfishes are well known for their possession of venomous spines. A fish which presents a scorpaenid appearance may gain the protection afforded by these formidable spines.

Clark and Gohar (1953: 44-45, 63) reported two possible examples of mimicry among plectognath fishes. The small filefish *Paraluteres prionurus* (Bleeker) was observed by Clark around coral reefs in the Palau Islands swimming with the sharp-nosed puffer *Canthigaster cinctus* (Richardson) which it resembled remarkably when its characteristic first dorsal fin was not held erect. The little puffer is believed poisonous by Palauan natives. *Paraluteres arqat*

(Clark and Gohar), described from a single specimen from the Red Sea, has a similar body shape and color markings to the common *Canthigaster margaritatus* (Rüppell). A laboratory test on a small sample of *Canthigaster* flesh from the Red Sea was considered inadequate, but the viscera were shown to be strongly poisonous. Randall and Brock (1960) have demonstrated that *Canthigaster* may at times be eaten by groupers in the Society Islands. Small puffers of unidentified species of *Canthigaster* were found in the stomachs of three specimens of *Epinephelus merra* Bloch. Two specimens of *C. margaritatus*, 25 and 30 mm in length, were removed from the stomach of a 205 mm specimen of *Cephalopholis miniatus* (Forskål).

Reporting that *Canthigaster* may be preyed upon by fishes is not intended to dispel Clark and Gohar's suggestion of mimicry, for it seems likely that their puffer-filefish examples are valid. The avoidance of *Canthigaster* by some predators or even the partial avoidance by some may nevertheless afford sufficient selection pressure by which mimicry could evolve. Possibly, juvenile or subadult canthigasterids are not toxic or these puffers are poisonous only during a certain season of the year. Even if both juveniles and adults are always toxic, occasional ones may be ingested by other fishes. Further investigation of the toxin of *Canthigaster* and the effect on predaceous fishes would be of interest.

Knipper (1955) described an example of collective mimicry of fishes from a large tidepool in East Africa. A swarm of dark juvenile catfish, *Plotosus anguillaris* (Bloch), averaging 28 mm in length, arranged themselves in a radially symmetrical mass with heads pointed outward and appeared like a black sea anemone with waving tentacles (Breder, 1959: 406, 413 erroneously interpreted Knipper's example as resemblance to a sea urchin). The compact group of little fish was all the more conspicuous, for it was seen against a white background. The mass was observed to expand and contract within limits in diameter of about 13 to 15 cm and 20 to 23 cm. When a foot was placed close to the aggregation, the fish took on a crescent shape but kept together. This species of catfish possesses venomous spines. Apart from the survival value of appearing like a sea anemone, the little fish may gain protection by presenting their spines *en masse* to an enemy. Mortensen (1917: 62, Fig. 2) observed a group of this species of catfish, each about 45 mm in total length, which appeared like a conspicuous black ball rolling over the coral in the Philippines.

He caught most with one stroke of a handnet. The first one he touched spined him painfully in the finger, the pain lasting long after the fish was detached.

Springer (1957) reported another possible case of collective mimicry from Tortugas Harbor. While night lighting, he and an associate observed a school of *Jenkinsia lamprotaenia* (Gosse) so compact that they thought it was a large single organism. It most suggested a ray to them. About 2500 fish weighing 25 lbs. occupied a volume less than a cubic foot. The school did not develop under influence of the night light but appeared fully formed when first seen coming in from surrounding waters. Each fish had a reddish blotch on top of its head which gave the mass a red-spotted appearance.

MIMICRY OF *Thalassoma bifasciatum* BY *Hemiemblemaria simulus*

A case of mimicry involving the blenny *Hemiemblemaria simulus* Longley and Hildebrand and the wrasse *Thalassoma bifasciatum* (Bloch) was described from Tortugas, Florida by Longley and Hildebrand (1940). The mimic, *H. simulus*, was noted to leave the bottom, where it was often seen with "head protruding from the burrow of some dead boring mollusk," and swim freely with the model, *T. bifasciatum*. The blenny swims smoothly with pectoral fins like a labrid, in contrast to the jerky, hesitating movements typical of the Blenniidae and Clinidae. It closely matches the yellow color phases of *T. bifasciatum* (with or without mid-dorsal and mid-lateral black bands and the larger *nitidum* phase with a series of large rectangular black blotches on the side) (Fig. 1). *H. simulus* "seems to be a more or less tolerated form like *Thalassoma bifasciatum* whose common exercise is the removal of ectoparasites from other fishes."

Although Longley and Hildebrand did not find fish parasites in the stomachs of *T. bifasciatum*, our analysis of the stomach contents of 32 specimens from 29 to 63 mm in standard length from Florida and the Virgin Islands revealed occasional crustacean ectoparasites of fishes, primarily small isopods. Most stomach material consisted of free-living, pelagic crustaceans, especially copepods.

The senior author and Walter A. Starck, II observed individual *H. simulus* in the company of *T. bifasciatum* over reefs in the Florida Keys. The blennies could be distinguished only by carefully watching

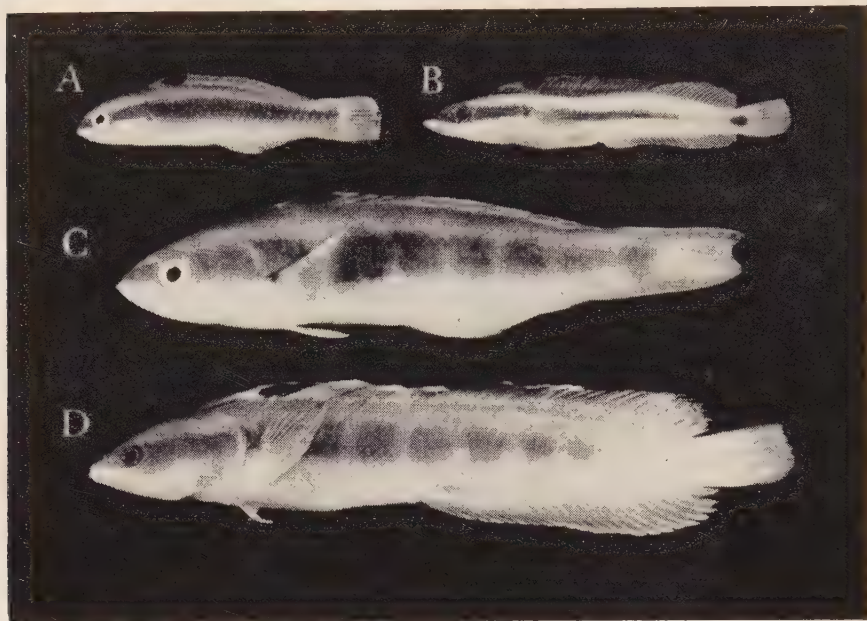


FIGURE 1. A. *Thalassoma bifasciatum*, 31 mm. B. *Hemiemblemaria simulus*, 39 mm. C. *T. bifasciatum*, 61 mm. D. *H. simulus*, 74 mm.

for their more slender form and different-shaped head. Even if allowance is made for overlooking occasional blennies because of their great similarity in both appearance and behavior to the wrasse, it is still readily apparent that *H. simulus* is rare by contrast to *T. bifasciatum* which is among the most abundant fishes on Florida and West Indian reefs.

Ten specimens of *H. simulus* were collected by J. Randall and Starck in the Florida Keys and their stomachs opened. Four from 32 to 39 mm contained free-living copepods. Three from 27 to 43 mm had eaten 2.5 to 5 mm mysid shrimps of the species *Mysidium columbiae* (Zimmer) (identified by Thomas E. Bowman). One of these contained, in addition, the head of about a 12 mm labrid fish. A 35 mm blenny contained a partially digested elongate fish 17 mm in length which appears to be a microdesmid. A 66 mm specimen contained a half-digested pomacentrid fish 13 mm in standard length. A 57 mm one from the Keys and a 74 mm one from the Bahamas collected by Starck were empty.

The basis for the mimicry would seem to be the protection from predation afforded *T. bifasciatum*, and hence the mimicking blenny as well, by the labrid's habit of feeding on ectoparasites of other fishes. The wrasse does not enjoy complete freedom from predation, however. A 35 mm one was found in the stomach of a 250 mm specimen of the yellowfin grouper, *Mycteroperca venenosa* (Linnaeus), speared in the Virgin Islands and another from a 400 mm trumpetfish, *Aulostomus maculatus* Valenciennes, taken with rotenone in the Virgin Islands. Possibly *H. simulus* approaches small fishes more closely and preys upon them more readily because of its similarity to the nonpiscivorous *T. bifasciatum*.

MIMICRY OF *Labroides dimidiatus* BY *Aspidontus taeniatus*¹

The wrasse *Labroides dimidiatus* and the petrosclirtine blenny *Aspidontus taeniatus* are remarkably similar in general shape and color pattern (Fig. 2). Both are blue with a black lengthwise band which becomes broader as it passes posteriorly on the body. Barnard (1927: 749) noted the great resemblance of these two phylogenetically dissimilar species in South Africa. He observed two color forms of the labrid, one with and one without a dark stripe at the base of the pectoral fin. The blenny also displayed two comparable color varieties. Fowler (1903: 170) described the blenny with the stripe on the pectoral base from Zanzibar as a new species, *Aspidontus tractus*, but the validity of this variant as a species is questionable. Barnard stated that it would be premature to claim the similarity of the wrasse and blenny as a case of mimicry until observations had been made on their habits and on the possible poisonous qualities of one or the other.

Randall (1955: 144) reported on the collection of *Labroides dimidiatus* and *Aspidontus taeniatus* in the Gilbert Islands (both from a single rotenone station) and suggested that the blenny is the mimic and the wrasse the model because of the unusual food habits of the latter which should afford at least some protection from predation. The primary food habit of species of *Labroides* is the removal of crustacean ectoparasites from the bodies, fins, buccal and gill cavities of other fishes, including piscivorous species (for a more detailed account see Randall, 1958).

¹This subject was presented as a paper at the meeting of the American Society of Ichthyologists and Herpetologists at Stanford University in August, 1957. Since this section was written articles on this example of mimicry have appeared in *Z. Tierpsychol.* by Eibl-Eibesfeldt (1959) and Wickler (1960).

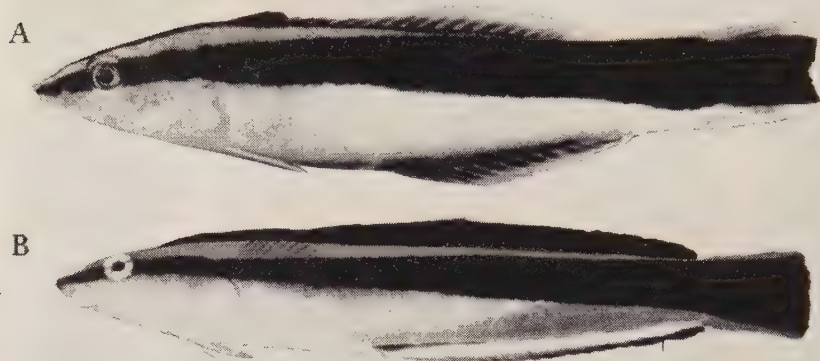


FIGURE 2. A. *Labroides dimidiatus*, 83 mm. B. *Aspidontus taeniatus*, 88 mm.

In Tahiti, in March, 1956, an attempt was made to spear a fish believed to be *Labroides dimidiatus*. Unlike previous wrasses of this species which had been similarly harassed, this fish ceased to swim in the usual labrid manner with its pectoral fins, erected its dorsal and anal fins, and wriggled rapidly to the reef where it backed into an old worm tube. The fish was captured from the tube and proved to be *Aspidontus taeniatus*. Subsequently, with careful underwater observation, it was possible to distinguish the two species (both fishes permit a swimmer to approach closely). The mouth of the blenny is not terminal as in the wrasse, but is ventral in position. The pelvic fins of *Aspidontus*, like other blennies, are jugular in position, instead of thoracic as in the labrid. Less fundamental, but more readily discerned is the greater tendency for body flexure in the blenny and a wrinkled condition of the dorsal and anal fins posteriorly. Also the blenny was never observed to swim in a peculiar manner, occasionally displayed by *Labroides*, in which the caudal fin is spread and the posterior part of the fish is oscillated up and down.

The blennies were usually seen near the locations on lagoon or bay reefs where one or more (often two) individuals of *Labroides dimidiatus* were consistently found. Although they may wander somewhat, species of *Labroides* generally remain in circumscribed areas. Reef fishes in the vicinity come to these sites for removal of their ectoparasites. By remaining near *L. dimidiatus* the blenny would seem to increase its protection based on its resemblance to the wrasse. As is

typical of Batesian mimicry, the mimicking blenny is less common than the model wrasse, which itself is far from being an abundant species. Often two blennies were seen together in one area.

The blue of juveniles of *Labroides dimidiatus* is considerably deeper and more brilliant than the blue of adults; the change in color from young to adult is a gradual one. The blenny displays a comparable change in its blue color with age.

In Makatea in the Tuamotus a pair of the labrids was observed with a dull orange-red area in the middle of the body just below the lateral black band. Two blennies of about the same size in the immediate vicinity displayed precisely the same variation in color pattern. Observations of the same color variation of *L. dimidiatus* and its duplication by *A. taeniatus* were later made on two occasions in the Society Islands.

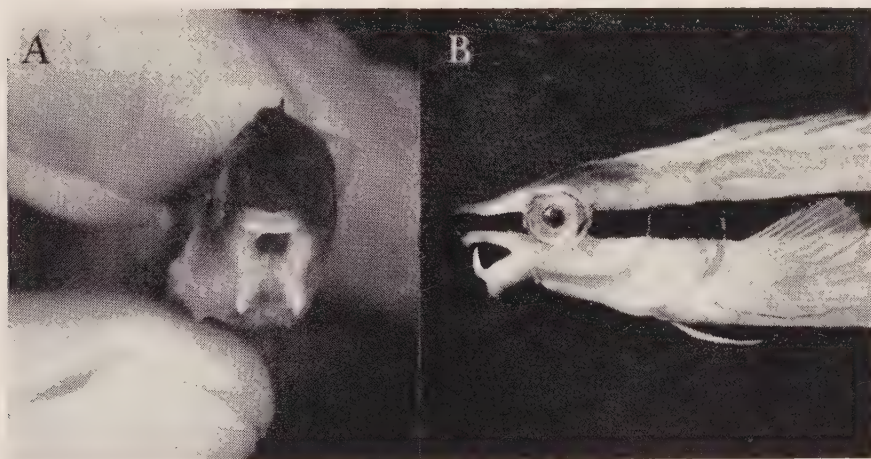


FIGURE 3. Dentition of *Aspidontus taeniatus*. A. Front view. B. Side view.

Barnard (1927: 749) stated that the blenny is a herbivore. Fishes feeding on benthic algae, such as surgeonfishes, graze almost continuously during the day. It was soon apparent that *A. taeniatus* in the Society Islands, at least, does not feed on benthic algae. Nor is the dentition (Fig. 3) typical of a plant feeder. In addition to small, close-set teeth, there is a pair of enormous canine teeth in the lower jaw which fit into sockets laterally on the roof of the mouth.

From January to May, 1956, 12 adult specimens of the blenny were

TABLE 1
STOMACH CONTENTS OF ADULT *Aspidontus taeniatius*

Standard length (mm)	Sex	Stomach contents
80	female	Bits of membrane and slender spines of the fins of a fish and remains of a sabellid worm tentacle.
54	female	Three fin rays with attached membranes; small spherical eggs, and a small amount of sand.
60	female	Pieces of the fins of two species of fishes (one piece yellowish brown, the others black).
68	female	Sabellid worm tentacles.
79	female	Five pieces of the soft portion of the fin of a fish (the pieces black and nearly circular, the largest 6.5 mm in diameter).
68	male	Numerous elongate fish eggs with adhesive disks at one end (probably pomacentrid eggs).
94	female	Same as above.
83	male	Sabellid worm tentacles.

spearred in Tahiti and Moorea for stomach content analyses. The viscera were torn out of two of the specimens by the spear, and two others had empty stomachs. The contents of the stomachs of the remaining eight specimens are given in Table 1.

The 54 mm female of Table 1 was observed to bite repeatedly at coarse sand on the bottom at a depth of 15 feet just before it was collected. It is believed that it was feeding on an egg mass, because eggs were later recovered in its stomach. Another blenny which was not captured was seen to feed voraciously on a mass of spherical fish eggs of about .5 mm in diameter which were located in a clump of red algae.

When first encountered in the blenny stomachs, the soft remains of sabellid worm tentacles could not be identified. Only after one fish was seen to slowly approach one of these tube worms and suddenly dart forward and tear off a tentacle before the worm could withdraw its tentacular crown, was this puzzling material identified as polychaete in origin. The species preyed upon was collected and sent to the U. S. National Museum where it was identified as *Sabellastarte indica* (Savigny) by Marian Pettibone.

The black pieces of fin found in the stomachs of the 60 and 79 mm blennies were probably torn from *Pomacentrus nigricans* (Lacepède),

the most common reef fish in Papetoai Bay, Moorea, where these two blennies were taken. On one occasion a blenny was observed to tear a piece of fin from a subadult of this damselfish. The attacking blenny approached the pomacentrid slowly in wrasse fashion. When only a few feet away, it swam with swift sinuous body movements to the fish, struck its fin, and withdrew with startling rapidity. A 60 mm blenny was speared directly after it was observed to rip a piece from the yellowish brown dorsal fin of about a 35 mm individual of the surgeonfish *Zebрасoma scopas* (Cuvier). The piece of fin was recovered from the blenny's stomach. Several other attacks by this species of blenny on fishes were observed, but it was usually not possible to ascertain if the blennies were successful in their attempts.

This manner of feeding would seem to be enhanced by the resemblance of *A. taeniatus* to *Labroides dimidiatus*. It may represent a second basis, via natural selection, by which the blenny simulated the color pattern and behavior of the wrasse.

Adult fishes, in general, are able to distinguish the blenny from the wrasse. When *A. taeniatus* approaches an adult fish, the latter usually swims warily away, keeping a distance greater than that which the blenny could traverse with a burst of speed. On a few occasions the larger fishes were seen to chase a blenny. Probably *A. taeniatus* succeeds more often in biting pieces of fin from juvenile fishes than from adults.

After learning the identity of an individual *Aspidontus taeniatus* in the New York Aquarium and being apprised of the food habits of the species, C. Ray (personal communication) wrote, "Sure enough, pieces of fins have been missing from some *Chaetodon*, *Heniochus*, and *Apogon*, all of one to two inches in length. The tail seems to be a favorite target."

Another species of petrosclirtine blenny, *Runula tapeinosoma* (Bleeker) was also seen nipping at other fishes and darting away. One 55 mm specimen was speared in Moorea, and small scales suggestive of those found basally on the median fins of many fishes, were found in its stomach. This slender fish has the annoying habit of swimming toward an underwater observer in an effort to bite. Fortunately, the fish is so small that usually only a slight touch is felt when it makes contact with the skin. Eibl-Eibesfeldt (1955: 212) observed *Runula albolinea* Nichols attack larger fishes in the Galápagos Islands.

The evidence for the mimicry of *Labroides dimidiatus* by *Aspidon-*

tus taeniatus may be summarized as follows.

Color

1. The duplication of the unusual *L. dimidiatus* color pattern by *A. taeniatus*.
2. Loss of brilliance of the blue color of *L. dimidiatus* with age matched by *A. taeniatus* of about the same size.
3. Minor color variation of *L. dimidiatus* noted as occurring in *A. taeniatus* in the same area.

Size and Morphology

1. Both species attain the same size and have similar body form.

Habitat

1. Both species found on shallow reefs of the protected waters of lagoons or bays.

Behavior

1. Wrasse mode of swimming with pectoral fins adopted by *A. taeniatus*.
2. *L. dimidiatus* is characteristically unafraid of swimmers and may be approached fairly closely. *A. taeniatus* exhibits comparable temerity.

Distribution

1. Both species are broadly distributed throughout the Indo-Pacific region from East Africa to French Oceania.

Relative Abundance

1. The mimic, *A. taeniatus*, is noticeably less common than the model, *L. dimidiatus*.

Food Habits

1. The parasite-picking food habits of *L. dimidiatus*, probably resulting in at least partial protection from predation, would seem to be the primary force in the development of the mimicry.
2. One of the food habits of *A. taeniatus*, the tearing of pieces from the fins of other fishes, would seem to be facilitated by the blenny's ability to closely approach other fishes, especially juveniles, in its guise of *L. dimidiatus*.

POSSIBLE MIMICRY OF *Centropyge flavissimus*

BY *Acanthurus pyroferus*

A second example of mimicry was encountered in Tahiti, although the basis for it remains obscure. In the harbor of Papeete a brilliant

yellow 43 mm specimen of a surgeonfish (Fig. 4A) was speared. When first observed underwater it was thought to be the angelfish *Centropyge flavissimus* (Cuvier, in C. and V.): only when a spine

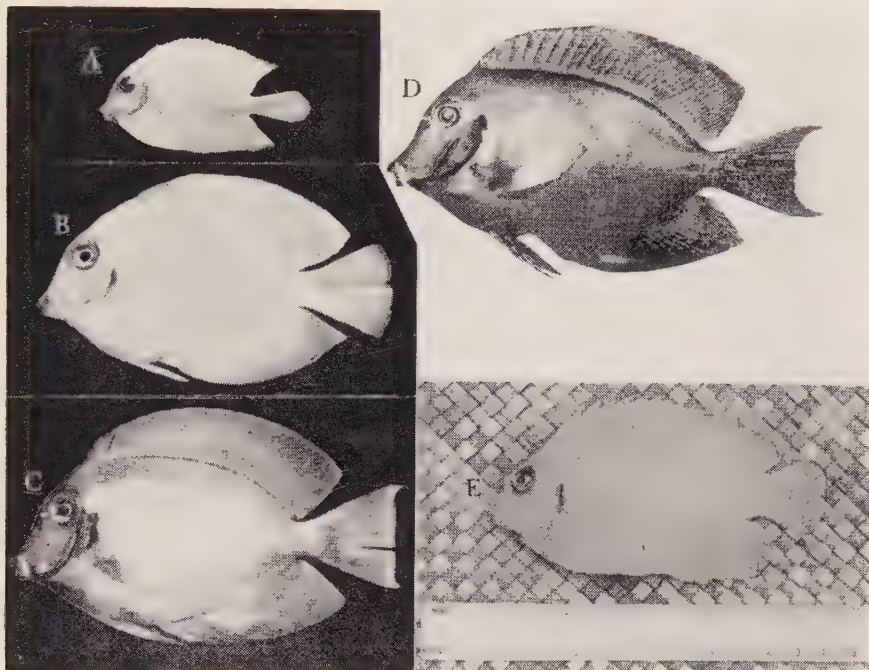


FIGURE 4. A-D. *Acanthurus pyroferus*. A. 43 mm. B. 70 mm. C. 88 mm. D. 113 mm. E. *Centropyge flavissimus*, 96 mm.

was noticed at close range laterally on the caudal peduncle was the fish recognized as a species of *Acanthurus*. The resemblance to the angelfish is striking. In addition to having deep, compressed bodies and chrome yellow ground color, both have a bright blue ring around the eye, a blue line under the mouth, a blue margin on the opercle, an orange patch just above the base of the pectoral fin, and pale margins and black submarginal lines posteriorly on the caudal fin and outer hind portions of the dorsal and anal fins. The caudal fins of both fishes are rounded. None of the 28 Indo-Pacific species of *Acanthurus* (Randall, 1956) possesses a rounded caudal fin as an adult, and no juveniles then known had such a caudal fin shape. Another specimen of the surgeonfish, 70 mm in standard length, with a less rounded caudal fin was procured and photographed (Fig. 4B). A

specimen of *C. flavissimus* of slightly greater size is shown in Figure 4E. Five specimens of *C. flavissimus* from 18 to 33 mm in standard length have a large blue-edged black spot in the middle of the body. No yellow acanthurids this small were observed.

The yellow surgeonfish have eight dorsal spines, a number then found on only two species of *Acanthurus*, *A. pyroferus* Kittlitz, the young of which was not definitely known, and *A. sohal* (Forskål), a Red Sea endemic. (Since the collection of these specimens, a new species of *Acanthurus* with close affinities to *A. pyroferus* has been described from the Caroline Islands; it has eight dorsal spines and a rounded caudal fin when young [Randall, 1960]). It was concluded that this fish was either the young of *pyroferus* or an undescribed species. A month later an 88 mm specimen (Fig. 4C) was collected in the harbor which clearly established the yellow ones as juveniles of *pyroferus*. It was brownish yellow and the lobes of the caudal fin were just beginning to form. The adult *pyroferus* (Fig. 4D) is dark brown with a strongly lunate caudal fin that has a characteristic broad light yellow band posteriorly.

If this represents an example of mimicry, then it would seem more likely that the surgeonfish is the mimic and the angelfish the model, for it is the former which develops a color pattern and caudal fin shape as a juvenile only to lose these at a size greater than that attained by adult angelfish. Adults of *A. pyroferus* reach a length nearly twice that of *C. flavissimus*. The angelfish, at least in the Society Islands and Tuamotu Archipelago, is more common than the surgeonfish. In a poison station with three gallons of five per cent liquid rotenone in Papetoai Bay, Moorea, 19 *C. flavissimus* (the largest of which is 71 mm in standard length) and two adult *A. pyroferus* were collected. Judging from underwater observation this would seem to approximate the true ratio of the two species in the bay. Of the four Tuamotu islands visited by the authors, Takapoto was the only one where *A. pyroferus* was seen at all, and it was rare there. *C. flavissimus* was common at all four islands. Of the two species, *A. pyroferus* is notably warier. Although hardly bold, the angelfish seems less prone to retreat into holes in the coral than most reef fishes.

The basis of the alleged mimicry remains unknown. One would expect, *a priori*, that the gaudily colored *C. flavissimus* advertises some quality distasteful to predators. An attempt was made to demonstrate any possible immunity from predation enjoyed by *C. flavissimus* at Takaroa in the Tuamotus (in lieu of the more populous Society

Islands because of the greater abundance of predaceous fishes such as serranids, lutjanids, and carangids in the Taumotus and the clearer water). Small individuals of *C. flavissimus* were speared, placed on hook and line, and lowered to the bottom at the edge of the pass (up to a maximum of 30 feet, for this species of angelfish is not common in deeper water). It was soon evident that some larger fishes would not hesitate to strike at the hooked angelfish. The most common piscivorous fish at the edge of the pass, *Cephalopholis argus* Bloch and Schneider, most frequently hit the bait, and four were caught. On two occasions *Epinephelus fuscoguttatus* (Forskål) struck the angelfish as did on another occasion an unidentified spotted epinepheline. Before a grouper arrived on the scene, triggerfish of the species *Balistapus undulatus* (Mungo Park) would often bite small pieces from the bait. When *C. flavissimus* was lowered near the snappers *Lutjanus vaigiensis* (Quoy and Gaimard), *Lutjanus gibbus* (Forskål), and *Lutjanus monostigmus* (Cuvier, in C. and V.), all known to feed in part on small fishes, they disdained to take the bait although some swam close to investigate. This cannot be construed as convincing evidence that these fishes do not normally prey upon this species of angelfish, for these snappers are much less inclined to take a hook than groupers, especially in daylight hours.

In the belief that the angelfish may be preyed upon to a lesser degree than other reef fishes of comparable size and shape, a line with two hooks was lowered, one baited with *C. flavissimus* and the other with either the surgeonfish *Zebrasoma scopas*, the only surgeonfish of approximate length to the angelfish commonly found at the time, or the damselfish *Pomacentrus nigricans*. There seemed to be no preference by the preying fishes for one fish or the other; generally the bait on the lower hook was struck first.

Although the above observations would seem to refute the hypothesis that *C. flavissimus* is avoided by piscivorous fishes, the possibility that this angelfish possesses some feature which would discourage normal predation has not been completely excluded. Wounded with a spear and attached to a hook and line, the angelfish did not represent typical prey. Certainly the slow-swimming *Balistapus undulatus* would not ordinarily feed on *C. flavissimus*. The following constitutes negative evidence, nevertheless it may be worth while to note that no *C. flavissimus* were perceived among the stomach contents of 1,305 groupers (primarily *Epinephelus* spp. and *Cephalopholis* spp.) and snappers (primarily *Lutjanus* spp.) from the Society

Islands and Tuamotus. Due to rapidity of digestion only 157 fishes of the many found in stomachs of these species could be positively identified to genus or species (Randall and Brock, 1960).

Another possible basis for the mimicry than some repugnant quality of *C. flavissimus* is that it may feed part of the time or at one phase of its life on ectoparasites of other fishes. This was not suspected while the authors were in French Oceania, for the angelfish were never seen picking at the bodies of other fishes but were often observed grazing on reefs. While diving in the Bahamas, the "cleaning" of fishes by juveniles of species of *Holocanthus* and *Pomacanthus* was pointed out by Conrad Limbaugh, and the authors have since recovered parasitic copepods from the stomachs and intestines of West Indian angelfishes of both of these genera. Algae and some sponge predominated in the gut contents, however. The gut contents of 50 specimens of *Centropyge flavissimus* from the Society Islands and Marshall Islands, from 18 to 103 mm in standard length, were examined for ectoparasites. None was found. Most of the food material was algal with some sponge; very little inorganic sediment was present. The alimentary tract is typical of a herbivore in its length (a specimen 98 mm in standard length has a 375 mm gut) and there is a large caecum. The stomach contents of three specimens of *A. pyroferus* from 44 to 89 mm consisted of fine sand and groundup algae. The round stomach of this fish is thick-walled and muscular and probably acts like a gizzard. The fine sand that is ingested assists in the trituration of the algae.

There is, therefore, no evidence that *C. flavissimus* removes ectoparasites from other fishes, other than by inference from related genera in the tropical Atlantic.

Although not promising in this case, the concept of Müllerian mimicry might be briefly considered. If two species of fish with attributes objectionable to predators have like form and color pattern, the advertisement of these attributes is furthered by their combined "effort." Since no obvious repelling quality could be found for *C. flavissimus* alone, it is no easier to find such for both species. The only possibility is that these fishes are spinous, and each has a spine characteristic of their respective groups as well, the preopercular spine of angelfishes and the caudal spine of species of *Acanthurus*. At least one species of *Acanthurus*, *A. lineatus* (Linnaeus), possesses a poisonous caudal spine (Randall, 1959).

Although the authors have no good explanation for the apparent

mimicry of *Centropyge flavissimus* by *Acanthurus pyroferus*, it would seem more likely that a biological basis remains to be found rather than assume that so remarkable a similarity of two fishes could have arisen by chance alone.

POSSIBLE EXAMPLES OF MIMICRY INVOLVING HAMLETS
(*Hypoplectrus* spp.)

Hypoplectrus gemma Goode and Bean, a small serranid fish recorded to date only from the waters of southern Florida, bears a strong resemblance to the brilliant blue *Chromis cyanea* (Poey), a pomacentrid fish known from Florida and the West Indies (Fig. 5). The hamlet possesses not only the same blue color of the damselfish

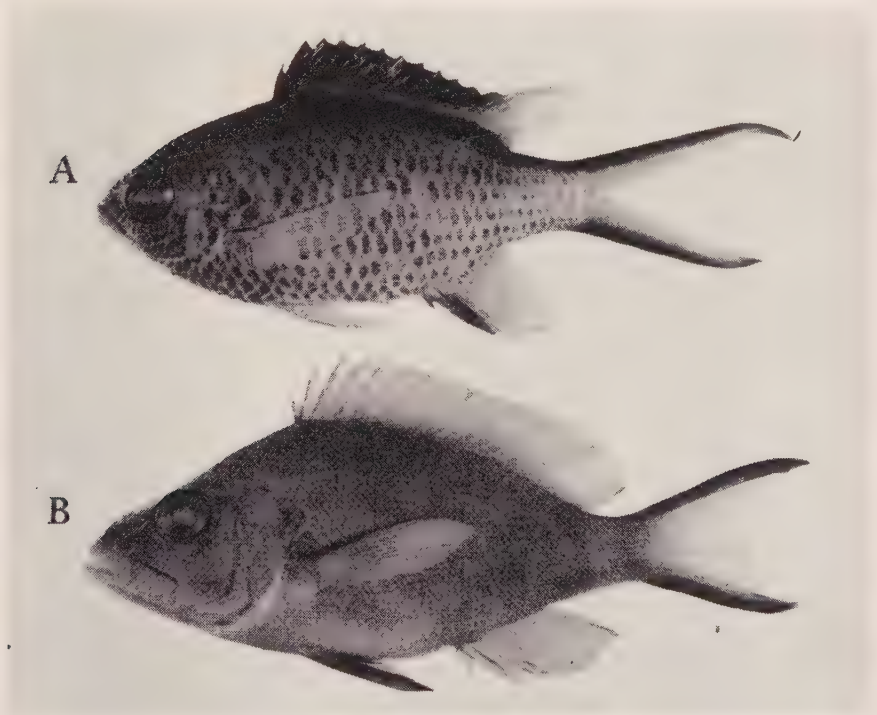


FIGURE 5. A. *Chromis cyanea*, 77 mm. B. *Hypoplectrus gemma*, 89 mm.

but also the characteristic black upper and lower lobes of the caudal fin. In addition, it has the most deeply incised caudal fin of all species of *Hypoplectrus* and is slightly more elongate than the others. In the

Florida Keys where the two species were observed together at depths of about 30 to 70 feet, the damselfish was perhaps twenty times more common than the hamlet. The hamlet is usually solitary, and at first glance, an observer is easily deluded into thinking he has seen another *C. cyanea*. This delusion is furthered by the mode of unhurried swimming of *Chromis* and *Hypoplectrus*; both use primarily their pectoral fins. *C. cyanea* is usually seen in small feeding aggregations several feet above the bottom. The fish pick small animals from the plankton, and their stomachs contain mostly tiny copepods (some were found in which small pelagic tunicates dominated the stomach contents). With the approach of danger the damselfish descend to the bottom. Hamlets feeds mostly on benthic crustaceans of moderate size such as crabs, shrimps, and stomatopods and occasionally on small fishes and polychaetes.

If mimicry is involved in this case, *H. gemma* is most likely the mimic, for it is less common and it exhibits a slight departure in caudal fin shape and body depth from that typical of other species. Also, the color pattern is unusual for the genus. The underlying principle for the alleged mimicry needs elucidation, however. The damselfish has been found in the stomachs of predaceous fishes, and there is no reason to suppose that it is a protected form. Perhaps the impetus to the development of a mimetic relationship arose from the ability of *H. gemma* to get closer to its prey in its guise of *C. cyanea*. Prey of the size captured by *Hypoplectrus* are never ingested by the small-mouthed *Chromis*.

Three species of *Hypoplectrus* have been observed in the Virgin Islands which are similar to certain pomacentrid and acanthurid fishes. Although less impressive than the *H. gemma*-*C. cyanea* example, which itself is not conclusive, these resemblances warrant brief mention.

First, the existing systematic problem with *Hypoplectrus* should be pointed out. Most authors (Longley and Hildebrand, 1941, being a notable exception) prefer to treat the complex as a single, highly variable species, *Hypoplectrus unicolor* (Walbaum). Some, such as Jordan, Evermann, and Clark (1930) have given subspecific designations to the different forms. Certainly this is not tenable, for they are not geographical variants. It is our belief that many of the variants, including the three with which we are concerned, will ultimately be shown to be species. One of them, *H. nigricans* (Poey), does appear distinct from the most common West Indian form, *H. puella* (Valen-

ciennes, in C. and V.) (it seems likely that *unicolor* and *puella* are different species). *H. nigricans* has a larger average size; of 31 collected in the Virgin Islands, mostly by spearing, 22 exceeded 100 mm in standard length and ranged as long as 122 mm. The longest of 53 specimens of *puella* collected in the same stations is 97 mm. Also, *nigricans* appears to have a slightly higher average number of gill rakers on the lower limb of the first arch.

H. nigricans is a dark brown fish with a bluish cast, especially ventrally; its pelvic fins are marked with blue and the pectorals are pale yellow. When seen underwater, it often conveys a first impression of a surgeonfish (*Acanthurus* spp.).

H. chlorurus (Valenciennes, in C. and V.) is dark brown with a bright yellow tail. It is easily mistaken for the adult of the common damselfish *Microspathodon chrysurus* (Cuvier, in C. and V.).

The third species appears to lack a specific name. It is dark brown on the upper half of the body shading gradually to orange-yellow on the ventral half. All the fins except the dorsal are orange-yellow, the pelvics being edged laterally with blue. The dorsal is brown, shading posteriorly to yellowish brown. This fish can be confused with adult *Pomacentrus variabilis* Castelnau or adult *P. planifrons* Cuvier, in C. and V.

The fishes which these three hamlets resemble are either herbivorous or omnivorous, and if the latter, they do not take prey as large as that of *Hypoplectrus*. Admittedly the resemblances are imperfect, but they have served to mislead man, at least. Breder (1946: 25) has defended the drawing of conclusions concerning deceptive resemblances of animals based on the visual sense of man.

RESEMBLANCE OF YOUNG *Novaculichthys taeniourus* TO FLOATING ALGAE

In late May, 1956, the junior author noticed independent movement in what, at first glance, appeared to be a small mass of floating green algae while wading in shallow water on a sand bottom in Papetoai Bay, Moorea. On close observation the algae revealed itself to be a small green fish about an inch long. When about to be captured in a net, it escaped by diving into the sand.

On June 14 either the same fish or another of the same species was seen in the bay near the first locality. Its resemblance to a mass of filamentous algae being carried back and forth in the slight surge was amazing. The fish was translucent green with dark brown lines

and white blotches. The elongate anterior rays of the dorsal fin and extensions of green into the dorsal and anal fins conveyed the impression of algal fronds. The fish's body was not maintained in a rigid condition but flopped from one side to the other with the surge. When approached slowly, it was able to move away without materially altering its plant-like guise. The type of algae most often seen free in the water which the fish most closely resembled was the blue-green *Hormothamnion enteromorphoides* Grun (a sample was sent through M. Doty to F. Drouet who provided the determination). The fish was caught by noting the place in the sand into which it darted and digging a dip net into the sand at this site. It proved to be a 28.5 mm wrasse of the species *Novaculichthys bifer* (Lay and Bennett) (= *Novacula kallasoma* Bleeker), and is shown in Figure 6A. The species is portrayed in color in Jordan and Evermann (1905: Pl. 41). Two other

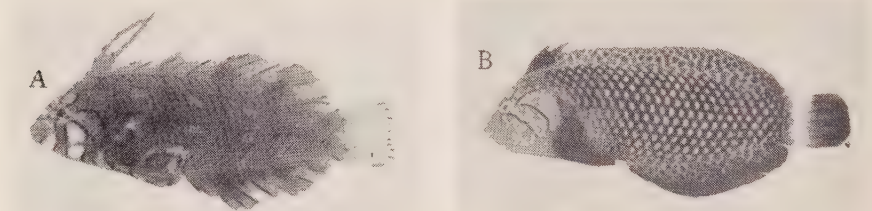


FIGURE 6. A. *Novaculichthys taeniourus*, 28.5 mm.

B. *N. taeniourus*, 94 mm.

specimens were taken later, one of about the same size over a shore reef in the Moorea lagoon at a depth of 5 feet and the other, a 44 mm specimen, from 4 inches of water on a sandy beach in the lagoon. The specimen from the reef was more brown than green. Both looked like floating plant material.

When removed from the water these little fish lost some of their resemblance to algae, and it was realized that the delusion had in a large part been effected by the behavior of the fish. Other fishes are known, such as the sea dragon *Phyllopteryx* and certain antennariids (Cott, 1957: 341, Figs. 70-72) and the giant kelpfish *Heterostichus rostratus* Girard (Holder, 1907; Hubbs, 1920) which have achieved a greater morphological similarity to algae than *Novaculichthys*.

On July 23, 1956, a 94 mm specimen of *Novaculichthys taeniourus* (Fig. 6B) was collected with rotenone in shallow water in Tahiti which links *N. bifer* to adult *N. taeniourus*. The first two dorsal rays

are intermediate in length to those of juvenile and adult specimens (which attain about 300 mm in length). The greenish white spots in the centers of the scales of the specimen alter to pale vertical lines on adults. Although recognizing *bifer*, de Beaufort (1940: 72) wrote, "I think it quite possible, that *bifer* is the young stage of *taeniurus*." Upon discussing the apparent identity of *bifer* and *taeniurus* with L. P. Schultz of the U.S. National Museum, it was learned that he has a large series of specimens which clearly show the transition from the *bifer* form to *taeniurus*. This has since been published (Schultz in Schultz *et al.*, 1960).

Adults of *taeniurus* were observed in shallow water on reef flats in the Society Islands and Tuamotus. They were wary of swimmers and usually swam rapidly away just above the bottom with their bodies tilted to one side. In a tank in the Honolulu Aquarium one was observed to dive into sand during daylight hours. This species is prone to bite when handled.

RESEMBLANCE OF YOUNG *Hemipteronotus pentadactylus* TO LAND PLANT DEBRIS

On the same day and at the same locality that the 28.5 mm specimen of *Novaculichthys taeniurus* was collected, the junior author observed another small labrid fish that provided an additional example of protective resemblance. It looked like a dark fragment of an old



FIGURE 7. *Hemipteronotus pentadactylus*, 35 mm.

coconut palm leaf or a piece of dark brown bark from a tree. Like the small *Novaculichthys*, it was seen in shallow water over sand far from the shelter of rock or coral. It held its body stiffly and allowed itself to be carried back and forth by wave action, but it was able to make slow evasive movements with the transparent outer part of the caudal fin and the pectoral fins, the motion of which is not easily detected. When pursued with vigor, it also dived head first into the sand. It was caught with a dipnet and is shown in Figure 7. It has about 8 rows of small scales on the cheek and the first two dorsal spines are connected by a low membrane to the rest of the dorsal fin. It appears to be the young of *Hemipteronotus pentadactylus* (Linnaeus). The specimen measures 35 mm in standard length and bears USNM number 114747.

RESEMBLANCE OF YOUNG *Hemipteronotus pavo* TO A LEAF

On November 28 at a depth of 2 feet over a dirty sand bottom near the first locality, a 56 mm wrasse was captured (Fig. 8) (USNM



FIGURE 8. *Hemipteronotus pavo*, 56 mm.

179888) which imitated a drifting leaf very effectively. It was dark brown, compressed, with a greatly prolonged first dorsal fin which was held forward over the head. The lappet-like membraneous extension at the tip of the fin looked like the swollen base of the stem of a leaf. The second dorsal and anal fins were extended. Like the juvenile *H. pentadactylus*, this fish allowed itself to be moved by the

surge, but unlike *pentadactylus* it permitted its body to bend slightly. It maintained a position about an inch off the bottom, lying first on one side and then the other. When approached slowly, the fish moved away, keeping approximately 3 feet in front of the observer. So skillfully was the movement accomplished that it seemed the fish was being carried by current. Only upon close inspection was it possible to discern the rapid fluttering of the nearly transparent pectoral fins and the slower vertical undulation of the clear hind portion of the caudal fin. When rapidly approached, the fish darted several yards away using its tail and posterior part of the body as most fishes do. It then resumed the leaf imitation behavior.

When an attempt was made to capture the fish with a dipnet, it escaped by diving into the sand, where it remained for about 10 minutes. It was caught after entering the sand a second time by carefully noting the point of entry and digging the net swiftly into the sand. The keeled head of this genus of fishes is probably a structural adaptation to facilitate burrowing into sand.

Figure 9 represents a 72 mm specimen of *H. pavo* taken with a spear in Tahiti. The dark color has given way to a dark and light banded phase. No observations were made on its behavior. A very

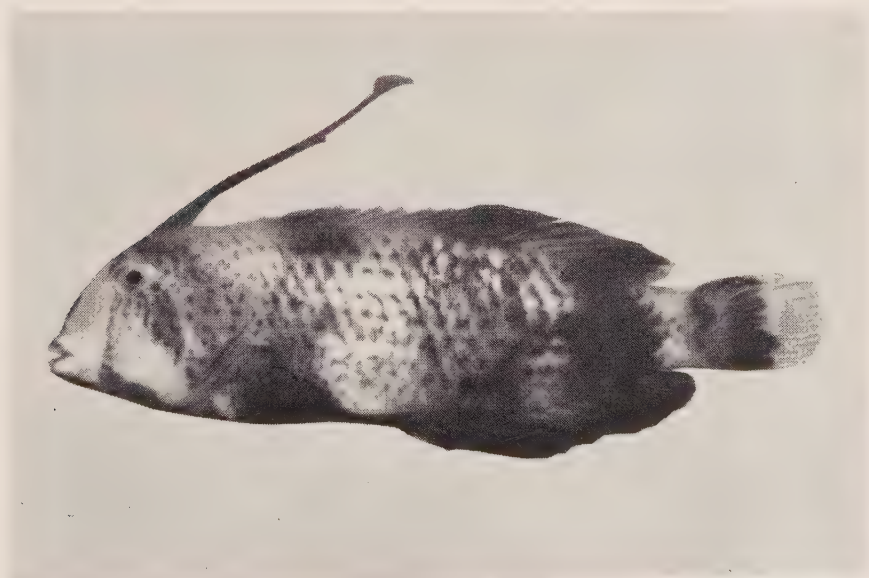


FIGURE 9. *Hemipteronotus pavo*, 72 mm.

large adult was purchased in the Papeete market. Its life color closely matched that of Color Plate 42 of *pavo*, as *Iniistius pavoninus* (Valenciennes), in Jordan and Evermann (1905).

FURTHER OBSERVATIONS ON THE RESEMBLANCE OF *Platax* TO DRIFTING LEAVES

The young of *Hemipteronotus* are not unique in their resemblance to a floating plant material. Other fishes which have adopted this mode of deception include the remarkable *Monocirrhus polyacanthus* Heckel (Arnold, 1912; Coates, 1933; Cott, 1957), of the waters of the Lower Amazon Valley, *Polycentrus schomburgki* Müller and Troschel (Beebe, 1945), also a South American fresh water fish, young *Oligoplites saurus* (Bloch and Schneider) (Breder, 1942), young *Lobotes surinamensis* Bloch (Breder, 1946; 1949), and juvenile *Platax* (Willey, 1904; Mortensen, 1917; Uchida, 1951).

Willey stated that when pursued, *Platax vespertilio* (Bloch) [= *P. orbicularis* (Forskål)] toppled over, feigned death, and sank inertly to the bottom where it looked like a yellow waterlogged jak leaf (*Rhizophora*). The authors observed young *Platax orbicularis* in the Society Islands which greatly resembled floating dead leaves, but noted a different reaction when the fish were pursued (see below). The fish were larger than those which Willey had watched, however. On December 14, 1956, in the Moorea lagoon in water from 1 to 2 feet deep over white sand, one of several large purau leaves (*Hibiscus tiliaceus* Linnaeus) which varied from yellow to brown in hue was noted to be moving more rapidly in the slow current paralleling the shore than the other drifting leaves. Upon careful inspection, the leaf materialized as a high-bodied, very compressed, yellowish brown *P. orbicularis*. This fish permitted a cautious approach to within about 15 inches. It retreated slowly by movements of the hyaline pectoral fins and outer clear portion of the caudal fin, but did not move its body which was tilted to one side about 45 degrees with the head angled downward. When an attempt was made to dipnet it, it eluded the net easily, swimming away in a conventional manner; in so doing it assumed a vertical position, raised its dorsal and anal fins higher than before, and lost much of its yellow color, appearing paler with vertical brown bands. It was finally captured with a spear. It measures 87 mm in standard length. A smaller specimen collected with rotenone in Tahiti was yellow. On May 9, 1957, at the wharf at Fare, Huahine, two more small fish (about 50 mm standard length) which were dark

brown were witnessed in their amazing pose of drifting leaves but not captured. They abruptly became pale yellowish anteriorly and displayed a brown band through the eye and another broader one just behind the head as they darted away from the hand of a swimmer which had advanced to within a few inches of them. Adults nearly two feet in length were infrequently seen in the Society Islands, usually in lagoons in 40 feet or more of water over sand, and a few were collected. As would be expected, they no longer resembled any drifting object in any way.

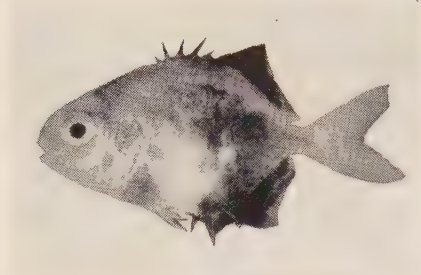
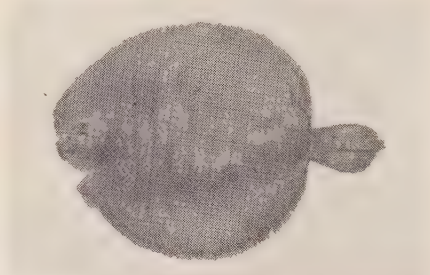
The 87 mm specimen of *P. orbicularis* has a body depth of 93 mm and a total height with dorsal and anal fins expanded of 230 mm. The teeth are numerous, attenuate, and tri-cusped with the central cusp much the larger of the three. The counts are as follows: D V, 39; A III, 28; P 18; gill rakers 9-1-9.

The young of another ephippid, the spadefish [*Chaetodipterus faber* (Broussonet)], have been likened to the black infertile seed pods of red mangrove (*Rhizophora*) and small black gastropods (Breder, 1946). Larger individuals not infrequently display a similar black phase and were seen to lie on one side on light colored sand, appearing like drifting trash (Breder and Rasquin, 1955: 85, Pl. 1). In the illustration, the shape of the fish is suggestive of a leaf.

The junior author observed about an 80 mm spadefish in August, 1960 allowing itself to be carried to and fro in the slight surge in Lameshur Bay, St. John, Virgin Islands. The fish was seen just off the bottom in about 2½ feet of water. It was very conspicuous against the white sand and resembled a sunken leaf. When approached, the fish erected its dorsal fin and swam swiftly several feet away where it resumed its lethargic role.

RESEMBLANCE OF YOUNG *Trachinotus falcatus* TO A FLOATING LEAF

On July 26, 1959, at the same locality that the young spadefish was seen, the senior author's hand swept near a small dark object lying at the surface which looked like a blackish leaf. Only when the object made an evasive movement was it realized that it was a small carangid fish. The fish alternated every few minutes between curving its caudal fin and posterior part of the body to one side and then the other. The tail was curved to the extent that it slightly exceeded an angle of 90 degrees to the anterior half of the body. In this flexed position the fish

FIGURE 10. *Trachinotus falcatus*, 28 mm.FIGURE 11. *Gymnachirus williamsoni*, 44 mm.

was still capable of slow progression by rapid fluttering of the transparent caudal and pectoral fins. The fish's progression seemed effortless, however, and close observation was necessary to detect fin movements. Even when essentially stationary, the fins could be seen to flutter. When pursued, the fish abandoned its curved attitude and fled by rapid vibration of the tail. Nevertheless it was possible to catch it by hand. It proved to be the young of the permit, *Trachinotus falcatus* (Linnaeus), and measured 16 mm in standard length. The color enhanced the deception. The body was blackish dorsally, shading to deep bronze on the sides and ventrally, except the abdomen. The dorsal and anal fins were largely blackish. The bronze color of the sides extended to the posterior part of the head and to the median lateral portion of the otherwise pale caudal peduncle, at which location it was suggestive of the stem of a leaf. The little fish was placed in an aquarium where it swam about normally until disturbed, as by a sharp movement in its direction. It would then cease to swim and curl its body as it had in the sea. The second day a 50 mm ctenophore was placed in the aquarium, and the fish fed upon it voraciously. The next day live material from a plankton tow (small crustaceans, chaetognaths, and pteropods) was eaten. Subsequently the fish was fed daily on cut fish. It became progressively more difficult to frighten into its curved posture. On September 21, 1959 it died. It had grown to 28 mm standard length. It was preserved and a photograph taken (Fig. 10).

RESEMBLANCE OF *Gymnachirus williamsoni* TO A SUNKEN LEAF

Still another fish which bears a resemblance to a dead leaf of a land plant was chanced upon in the Virgin Islands by J. Randall and

T. Chess. On December 12, 1959, a 44 mm naked sole (Fig. 11) was observed in 3 feet of water inshore in Lesser Lameshur Bay on a white sand bottom near a bed of *Thalassia*. The fish was entirely black and looked like a sunken blackened leaf with serrate edges. It was sluggish and when prodded moved only a foot or two, coming to rest again on the sand. It was caught by hand.

The specimen was sent to C. E. Dawson who is revising the genus *Gymnachirus*. He identified it as a juvenile *G. williamsoni* (Gunter) which, he stated, may prove to be a synonym of *nudus* Kaup.

Breder (1955: 91-92, Pl. 1) observed small individuals of another soleid, *Achirus lineatus* (Linnaeus), which were solid black against a light sand background. One was placed in an aquarium with a light sand bottom. It disdained to cover itself with sand and usually lay in the center of the tank, fully exposed. If pushed with a rod, it would move off slowly. "It would so flute its marginal fins as to appear ruffled." At night the fish was paler and exhibited dark cross bands. Breder did not indicate the resemblance of this species of flatfish to blackened leaves; however, in the opinion of the authors, this constitutes a comparable example of protective resemblance to *Gymnachirus williamsoni*.

FURTHER OBSERVATIONS ON THE RESEMBLANCE OF THE YOUNG OF *Strongylura* AND *Sphyaena barracuda* TO FLOATING PLANT MATERIAL

Gudger (1929: 158) noted that the young of the houndfish, *Strongylura raphidoma* (Ranzani), markedly resembled broken bits of eel-grass (probably *Cymodocea*) at Tortugas, Florida. Breder (1932: 19) remarked on the fish's habit of lying in drifting flotsam and the similarity of a pale cream color phase to fragments of *Cymodocea* which become this tint as they die and decompose. Breder and Rasquin (1952: 18) mentioned that small *raphidoma* "hide" amid floating trash, usually small sticks which they closely resemble. They added that at no place were these fish undertaking this kind of "mimicry" at a greater length than 50 mm.

Although this observation may be true of *raphidoma*, another species of needlefish, *Strongylura timicu* (Walbaum), imitates floating pieces of manatee grass (*Cymodocea*) at lengths as great as 130 mm. This has been seen by the authors in bays in St. Thomas and St. John, Virgin Islands. The fish were never bright green like most floating pieces of the grass but were usually light yellowish gray, a color usually

exhibited by grass fragments covered with fine epiphytic algae. The individual fish are active and are usually detected by their movement. They often come to rest beside pieces of manatee grass and frequently adopt a pose with the body curved. Most fragments of grass in excess of about 50 mm are curved, hence the curved form of the fish adds to the deception.

The authors observed several small blackish individuals of *Strongylura* sp. averaging about 20 mm in length near docks at Coconut Island, Oahu, Hawaiian Islands, which could be distinguished only with difficulty from dark twigs among which they were floating.

Juvenile barracuda [*Sphyræna barracuda* (Walbaum)] also appear superficially like small floating sticks. A 21.5 mm one was observed inshore in Papetoai Bay, Moorea, Society Islands, on June 12, 1956; an 18.5 mm one floated nearly vertically at Cat Cay, Bahamas, on May 4, 1958; one slightly larger was noticed in a mangrove slough at Cruz Bay, St. John, on July 31, 1959, but was not collected. The latter lay stiffly suspended just beneath the surface at an angle of about 45 degrees to the surface with its head up. A black band could be seen running from the snout through the eye to the base of the tail. This band broadened ventrally on the posterior half of the body. There were six saddle-like dusky spots dorsally on the body. The fins were hyaline and could not be easily seen. When disturbed, the little fish swam off horizontally.

THE RESEMBLANCE OF JUVENILE *Kyphosus sectatrix* TO *Sargassum*

On December 22, 1959, in St. Marc Bay, Haiti, the authors were collecting fishes with T. Chess when the latter noticed a small fish floating on its side at the surface on top of a large mass of *Sargassum*. The fish was the same color of brown as the *Sargassum* and had pale yellowish brown spots about the size and color of the bladders of this alga. The 44 mm fish was easily caught in a dipnet and was identified as *Kyphosus sectatrix* (Linnaeus) (Fig. 12). This color is unlike that of adults, which are usually silvery gray with lengthwise streaks of dull yellow. There is, however, a pale-spotted gray phase (Beebe and Tee-Van, 1933: Plate opposite page 162). Adults, which can attain 18 inches, generally live among rocks where there is some wave action and feed mostly on algae. Beebe and Tee-Van (1928: 166-167) recorded a single 78 mm specimen from Haiti and reported the food as small crustaceans. The stomach of the 44 mm specimen contained 29 free-living copepods from .6 to 3 mm in length.

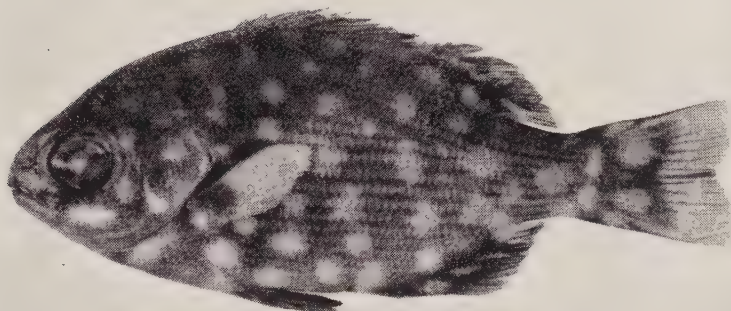


FIGURE 12. *Kyphosus sectatrix*, 44 mm.

RESEMBLANCE OF *Antennarius pauciradiatus* TO DEAD *Udotea*

On June 11, 1959, H. Kumpf discovered a 24 mm frogfish (*Antennarius pauciradiatus* Schultz) on a coral rubble bottom at a depth of 40 feet off Salt Pond Bay, St. John, Virgin Islands, which bore a marked resemblance to dead *Udotea*. This benthic green alga becomes white when it dies. The fish, which was seen near such a dead thallus, was also white. The *Udotea* waved slightly in the current, and the fish moved back and forth in unison with the alga. As the fish was approached, it made no effort to flee and was easily caught by hand. It is shown in Figure 13.

RESEMBLANCE OF JUVENILES OF *Monacanthus setifer* AND *Monacanthus ciliatus* TO ALGAE

While skindiving near Cow Bay, Jamaica, on December 20, 1959, a half-inch line leading from a fish trap in 40 feet of water to a wooden marker on the surface was grasped in one hand by the senior author. A small monacanthid fish which had not been seen previously was frightened a short distance away from the line. It returned and put its snout to the line where it blended perfectly with the luxuriant growth of algae, hydroids, etc. thereupon. By running the hand up and down the line, three other small filefish were dislodged from it. When approached free in the water, they curled their tails to one

side and moved slowly away. One swam into the midst of a small mass of detached algae and sank slowly with it. Two of the little fish were collected (Fig. 14). They measure 18.5 and 22 mm in standard length and have 28 soft dorsal and 27 anal rays. They



FIGURE 13. *Antennarius pauciradiatus*, 24 mm.

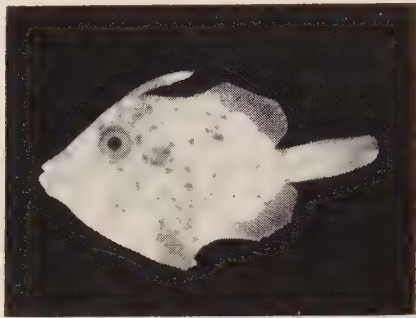


FIGURE 14. *Monacanthus setifer*, 18.5 mm.

were identified as *Stephanolepis setifer* (Bennett) (= *Monacanthus setifer*) by F. Berry.

On May 10, 1960, at a depth of 70 feet on a coral rubble bottom off Reef Bay, St. John, Virgin Islands, a 41 mm *Monacanthus ciliatus* (Mitchill) (Fig. 15) was observed hovering with its head down slightly above the bottom. Its tail was broadly spread and curved to one side; its pelvic flap was fully extended. The filefish was bright green and resembled species of *Udotea* and *Avrainvillea* which are common benthic plants in the vicinity. When the fish was approached slowly, it moved away slowly, still with its head down. Movement was accomplished by fluttering the pectorals and undulating the soft dorsal and anal fins. These fins are transparent and their movement is difficult to detect. The dorsal spine was at times held erect, at times partly depressed. When the fish came near a thallus of *Udotea cyanthiformis* Decaisne (identified by H. J. Humm) it took a position contiguous with the alga. It was more difficult to frighten away from this position than from locations away from the alga. When a hand was advanced rapidly to within about two inches of the fish, it would assume normal orientation and dart swiftly away. After moving about one foot, it would resume its head-down stance. This sequence was repeated many times during efforts to capture the fish. It was finally caught by herding it slowly into a clear plastic bag.

A 12.5 mm individual of this species of filefish was also encountered

at the same locality. It was green and maintained a head-down position whether immobile or moving away from the observer. It was caught by hand. Judging from the trace of silvery color on the abdomen, this small juvenile is probably not far removed from the post-larval stage.

Another small monacanthid, *M. tuckeri* Bean, was observed by the senior author in the Virgin Islands lying vertically with head downward among fronds of an unidentified plexaurid gorgonian. The color

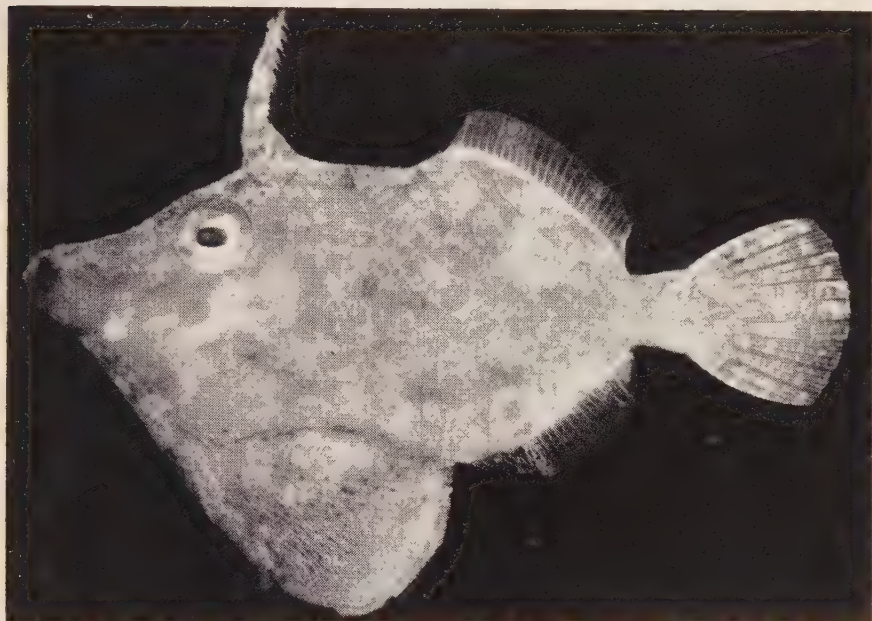


FIGURE 15. *Monacanthus ciliatus*, 41 mm.

of the filefish approximated that of the gorgonian. The fish remained near one of the fronds in spite of the swaying of the colony in the surge.

Breder (1946: 42) noted that small specimens of *Monacanthus hispidus* (Linnaeus) collected in a seine in a region of New York Harbor where *Ulva* was present were colored bright green like this alga. Mortensen (1917: 64-65, Fig. 3) included juvenile monacanthids among those fishes he observed floating passively, usually on their sides, at the surface with bits of driftwood. Uchida (1951) likened two other plectognath fishes to floating objects. Young trigger-

fish [*Canthidermis rotundatus* (Procé)] resembled pieces of pine bark, and juvenile porcupinefish (*Diodon holocanthus* Linnaeus) looked like drifting pumice stones.

RESEMBLANCE OF *Paraclinus marmoratus* TO A GORGONIAN

The clinid fish *Paraclinus marmoratus* (Steindachner) was observed by G. L. Voss at Soldier Key near Miami, Florida, on September 16, 1960 well concealed in a colony of *Pterogorgia anceps* (Pallas) at a depth of about 3 feet. This gorgonian is usually purple and is triangular in cross-section with whitish polyps extending from the corners. The fish, estimated to be 40 mm in standard length, aligned itself with one of the vertical fronds near the base of the colony with its head downward and its fins expanded. Although not purple, the fish was as dark as the coenenchyme of the gorgonian and the edges of the dorsal and anal fins were pale like the polyps. The fish disdained to move from its position until an attempt was made to grasp it by hand. It then moved a short distance away from the frond but soon returned to its former stance. It was finally caught in a glass jar. When placed in an aquarium it first aligned itself with the aerator hose which, being nearly transparent, afforded no concealment. It then nestled among some polyps of *Zoanthus*. The fish best known for its ability to lie concealed among gorgonians is the trumpetfish (*Aulostomus maculatus* Valenciennes) (Longley and Hildebrand, 1941: 66, pl. 1).

RESEMBLANCE OF JUVENILE *Mugil vaigiensis* TO BUBBLES

In February, 1956, in the harbor of Papeete, Tahiti, three small white objects were seen moving slowly at the surface, slightly more rapidly than would be expected for drifting objects. At first glance they were mistaken for bubbles. On closer inspection, this possibility was soon obviated. Nevertheless, the realization with still further scrutiny that the objects were fish came as a surprise, for they were unfishlike in color and behavior. When a net was advanced toward them, they retreated slowly. When an abrupt movement was made in their direction, they curled the posterior part of their bodies sharply to one side and remained motionless except for slight vibration of their caudal fins. On October 12, 1956, another group of three of these fish of about the same size were seen in Papetoai Bay, Moorea, and two were taken in a dipnet. They measured 8 mm in standard length and were identified as the young of the yellow-tailed mullet, *Mugil vaigiensis* Quoy and Gaimard.

Mortensen (1917: 66) observed small silvery white fishes, apparently of the genus *Atherina* (not distantly related to the Mugilidae), swimming in a peculiar irregular way on the surface at Panama. They looked like shining spots, and he stated, “. . . there is no doubt in my mind that they are mimicking the drops of water, so often seen floating for a while on the surface of the sea.” Probably he meant bubbles instead of drops of water.

RESEMBLANCE OF A GROUP OF MULLID FISHES TO BENTHIC ALGAE

In August, 1959, C. R. Robins observed about a dozen goatfish (Mullidae) in a group at the side of a concrete sea wall at Waikiki, Oahu, which were difficult to distinguish from attached clumps of algae (probably *Sargassum*). The water was about 3 to 4 feet deep and the observation began when tide was still flooding. The locality was subject to slight surge which made the clumps of algae sway back and forth. The fish, as a group, made the same swaying movements as the algae. Robins stated that he had to look closely to ascertain that they were indeed a group of fish and not a plant. Two of the fish served the role of holdfast, *i.e.* maintained a more-or-less fixed position on the wall. The others were arranged linearly about 18 inches out from the wall with individuals projecting outward like fronds from an axial stalk. As the column moved back and forth, it was noted that the fish did not maintain rigid positions, but considerable reorganization took place. At slack tide an hour later the water calmed, and the fish dispersed and began to feed.

Another example in which a group of fish resembled a mass of algae was noted by Crawford and Powers (1953) in New York Bight. Juvenile orange filefish [*Alutera schoepfi* (Walbaum)] formed a “rosette-like pattern with the heads of each fish pointed towards a common central point. In this position the school resembled an arrangement of floating portions of seaweed.”

The opportunity to carry out field work in the Society Islands was provided by a research fellowship from Yale University and the Bernice P. Bishop Museum. Most specimens from this area discussed in the paper have been deposited in the United States National Museum. Western Atlantic specimens are located at The Marine Laboratory of the University of Miami.

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SOME ACANTHOCEPHALAN PARASITES OF FLORIDA FISHES

WILBUR L. BULLOCK

Zoology Department, University of New Hampshire

ABSTRACT

Examination of 479 fish (25 species) resulted in the collecting of 5 species of Acanthocephala. Most of these fish were from the Cape Haze area but a few were collected near Miami. The species of acanthocephalans found were: *Floridosentis elongatus*, *Atactorhynchus verecundus*, *Neoechinorhynchus doryphorus*, *Telosentis tenuicornis*, and *Arhythmorhynchus uncinatus*. The host and geographic distribution of each parasite is considered.

INTRODUCTION

During the latter part of December, 1958 the viscera of 479 fish, representing 25 species, were examined for acanthocephalan parasites. Most of the fish were collected in the Cape Haze area of Florida and examined at the Cape Haze Marine Laboratory. Some fish were collected in the Miami region, preserved in formalin, and examined upon return to the University of New Hampshire. Five species of Acanthocephala were found in six species of fish from the Cape Haze area.

The writer wishes to express his sincere appreciation to Dr. Eugenie Clark for the use of the facilities at the Cape Haze Marine Laboratory and for her aid in the identification of some of the fish hosts. Thanks are also due to Mr. Oley Farver for his assistance in locating collecting spots and in supplying some of the fish hosts. I also appreciate the assistance of Dr. Hilary Moore and other members of the staff of The Marine Laboratory of the University of Miami.

Family NEOECHINORHYNCHIDAE

Floridosentis elongatus Ward, 1953.—This acanthocephalan was found in 5 of 10 striped mullet (*Mugil cephalus*). The infections were light; the maximum number of parasites from any host individual was 5. This is the first report of this parasite from the Florida west coast. *Floridosentis elongatus* has been reported from the Miami region by Ward (1953, 1954), from Puerto Rico by Cable and Quick (1954), and from southern Texas by Bullock (1957). It remains to be determined if this parasite occurs in the northern portion of the Gulf of Mexico.

Atactorhynchus verecundus Chandler, 1935.—*A. verecundus* was found in 16 of 191 sheepshead minnows (*Cyprinodon variegatus*). This worm was first described from Galveston Bay, Texas, by Chand-

ler (1935). It has since been reported from several localities covering nearly the entire Texas coast (Bullock, 1957). Its occurrence on the west coast of Florida probably indicates a distribution along the entire Gulf coast. Unfortunately, only 2 specimens of *C. variegatus* were obtained from the Miami region and these were negative for acanthocephalans. The closely related cyprinodontid (*Floridichthys carpio*) failed to yield any acanthocephalans although 44 individuals were examined from the Miami region and 2 individuals were examined from Cape Haze. It would be interesting to examine both of these species more intensively along the entire Florida coast.

Neoechinorhynchus doryphorus Van Cleave and Bangham, 1949.—Immature *N. doryphorus* were recovered from the mesenteries of one of 48 rainwater killifish (*Lucania parva*) and 2 of 10 minnows (*Notropis* sp.) seined in brackish water roadside ditches near El Jobean. This acanthocephalan was described by Van Cleave and Bangham (1949) from the intestine of the flagfish (*Jordanella floridae*) taken in nearby Englewood. At that time immature specimens of this species were reported from the mesenteries of *Fundulus majalis*. Therefore, the Cape Haze-Englewood region of Florida remains as the only reported locality for this neoechinorhynchid parasite. It would appear that this acanthocephalan is most likely a freshwater species but more information on the life cycle and host preference of this species is needed before it can be assigned to any specific habitat.

Family RHADINORHYNCHIDAE

Telosentis tenuicornis (Linton, 1892) Van Cleave, 1947.—*T. tenuicornis* was found in one of 3 pigfish (*Orthopristis chrysopterus*). This acanthocephalan is widely distributed in marine fishes from southern New England to the Caribbean. In contrast to the previously discussed neoechinorhynchids, these worms do not exhibit strict host specificity and have been reported from several families of fish hosts.

Family POLYMORPHIDAE

Arhythmorhynchus uncinatus (Kaiser, 1893) Van Cleave, 1924.—Over 50 specimens of *A. uncinatus* were recovered from the mesenteries of one of 3 sheepsheads (*Archosargus probatocephalus*). This parasite was first described as *Echinorhynchus uncinatus* by Kaiser (1893) from material collected in "Florida" from an unknown host. After considerable confusion in regards to the taxonomic identity of this species it was redescribed by Van Cleave (1924) as *Arhythmorhynchus uncinatus*. However, this redescription was based solely on

some of Kaiser's original material. To the writer's knowledge there is no other published reference to this species of *Arhythmorhynchus*. Golvan (1956), in his revision of the genus, merely lists "*A. uncinatus* — hôtes inconnus." While the definitive host of this species remains unknown, the occurrence of immature worms in the mesenteries of a marine fish indicates that the adult acanthocephalan could probably be found in some species of marine shore bird from the coastal region of southwest Florida.

DISCUSSION

The following fishes examined at Cape Haze did not harbor acanthocephalan parasites: *Adenia xenica* (15), *Floridichthys carpio* (2), *Fundulus chrysotus* (11), *Fundulus confluentus* (1), *F. grandis* (9), *F. similis* (20), *Jordanella floridae* (1), *Mollienisia latipinna* (8), *Gambusia affinis* (29), *Strongylura* sp. (1), *Paralichthys albiguttus* (1), *Lepomis macrochirus* (4), *Promicrops itajara* (2), *Mvcteroperca bonaci* (2), *Lutjanus griseus* (4), *Sciaenops ocellata* (1), and *Eucinostoma gula* (9).

No Acanthocephala were found in any of the 97 fish of 5 species collected in the Miami region. That this is largely due to inadequate sampling in a very limited time period is indicated by the report of Ward (1954). She describes 3 species of acanthocephalans from the waters near Miami. In this study, the following fishes were examined from the Biscayne Key area of Miami: *Floridichthys carpio* (44), *Fundulus grandis* (4), *F. heteroclitus* (4), *F. similis* (31), and *Fundulus* sp. (14).

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COPEPODS OF THE GENUS *OITHONA* FROM THE GULF OF MEXICO¹

GEORGE D. GRICE

Woods Hole Oceanographic Institution

ABSTRACT

Five species of *Oithona* (*O. plumifera*, *similis*, *brevicornis*, *nana* and *simplex*) are reported from the Gulf of Mexico. Their distribution is indicated and a key is presented for their identification.

INTRODUCTION

The genus *Oithona* (Copepoda: Cyclopoida) is frequently represented in marine zooplankton samples by one or more species and numerous individuals. In a monograph on the genus, Rosendorn (1917) recognized twenty species of *Oithona* and two other species of a related genus, *Paraoithona*. He presented figures of the species and provided taxonomic keys for their identification. Additional descriptions and keys are included by Kiefer (1929) and his treatment of the genus.

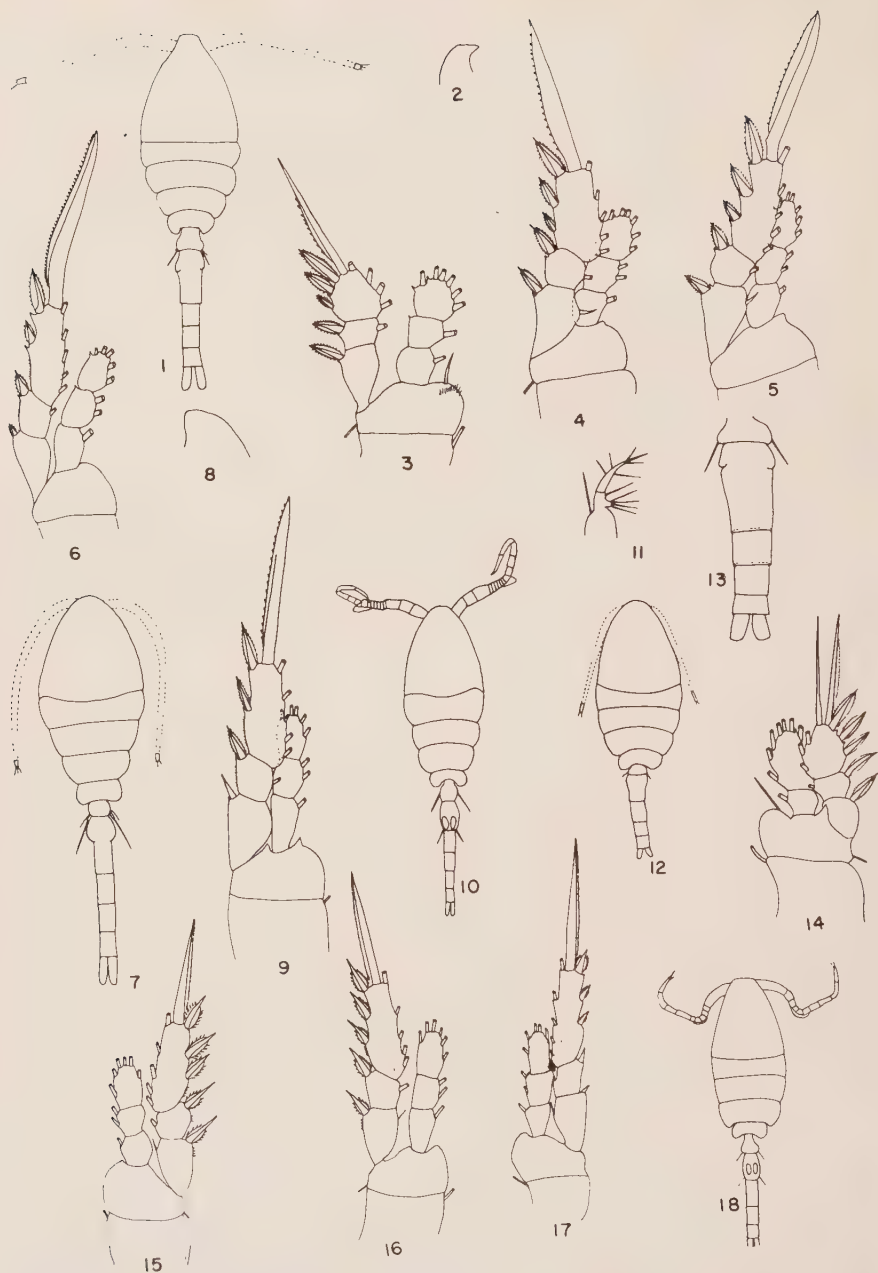
COLLECTING AND IDENTIFYING

Although the species of *Oithona* are widely distributed and occur in all types of marine environments (estuarine, neritic and oceanic waters), they may, nevertheless, be easily overlooked. This can result from the use of a coarse collecting net which permits them to escape through the mesh, or, when they are detected in a plankton sample, the confusion of two or more species because of their superficial similarity. As many of the estuarine and inshore-neritic species of *Oithona* are quite small (commonly 0.45 to 0.80 mm), it is necessary to use a fine mesh net in order to collect them. A No. 10 net is recommended for obtaining those species which occur along the Gulf coast. Once collected, the individuals need to be more or less completely dissected in order to make reliable determinations.

PREVIOUS RECORDS FROM THE GULF OF MEXICO

Five species of *Oithona* have been reported from the Gulf of Mexico. Four of these have been recorded from estuarine and neritic waters of the Florida west coast and one species from the Louisiana coast. These five species cannot, however, be considered as the sole representatives of this genus in the Gulf of Mexico. The cyclopoid

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FIGURES 1-18. *Oithona brevicornis* (total length, 0.6 mm). 1, female dorsal view; 2, tip of forehead, lateral view; 3, first foot; 4, second foot; 5, third foot; 6, fourth foot. *Oithona nana* (total length, 0.75 mm). 7, female, dorsal view; 8, tip of forehead, lateral view; 9, fourth foot; 10, male (total length, 0.60 mm) dorsal view; 11, second basipod segment of mandible. *Oithona simplex* (total length, 0.49 mm). 12, female, dorsal view; 13, posterior part of body; 14, first foot; 15, second foot; 16, third foot; 17, fourth foot; 18, male (total length, 0.47 mm) dorsal view. *O. brevicornis*, *O. nana* and the female *O. simplex* drawn from specimens collected three miles off Alligator Harbor in December, 1954. The male *O. simplex* drawn from a specimen collected three miles off the mouth of the Marco River in October, 1954.

copepods of waters beyond the continental shelf and of most neritic areas of the Gulf exclusive of the Florida coast have not been studied and it is probable that several additional species will be added when the plankton of these areas become better known.

NOTES ON THE SPECIES

Oithona plumifera Baird.—This species is an inhabitant of the off-shore waters of the Florida west coast. It is not likely to be taken nearer to shore than about ten miles except in the Panama City and Pensacola areas where several typical offshore species occur (see Grice, 1960). Although not figured here, *O. plumifera* is easily distinguished from the four other species. The female has a prominent rostrum which is visible in dorsal view and the male is distinguished by a combination of specific characters given in the key below. The total length of the female is about 1.3 mm while that of the male is about 0.9 mm.

O. plumifera has been reported from the Florida west coast by Davis (1950)), King (1950) and Grice (1960).

Oithona similis Claus.—This species has been reported by Foster (1903), who stated that he found it in St. John's Bayou and Calcasieu Pass on the Louisiana coast. There are no other records of it from the Gulf of Mexico. Rosendorn (1917) gives the length of female *O. similis* as 0.78 mm and that of male as 0.67 mm.

Oithona brevicornis Giesbrecht (Figs. 1-6).—This is a very abundant and widespread species. It occurs along the entire Florida west coast but chiefly in estuarine and nearshore waters. The female varies in length from .50 to .60 mm. The male of this species is apparently quite rare. Figures of this sex are given by Rosendorn (1917) and later by Wilson (1932a).

This species has been recorded from Alligator Harbor (Grice, 1956) and from the Florida west coast and Florida Keys (Grice, 1960).

Oithona nana Giesbrecht (Figs. 7-11).—I here follow Rosendorn (1917) and Kiefer (1929) in referring this species to the genus *Oithona* rather than to the genus *Oithonina* as first proposed by Sars (1918) and later diagnosed by Wilson (1932b).

O. nana is another widespread species which occurs in estuaries as well as in neritic waters of the Florida west coast. Like the above species, it is an abundant member of the copepod plankton. In length

the female varies from 0.58 to 0.76 mm and the male from 0.51 to 0.53 mm.

This species has been reported from Florida by Gunter *et al.* (1948), Davis (1950), Davis and Williams (1950), King (1950) and Grice (1956, 1960).

Oithona simplex Farran (Figs. 12-18).—Gulf of Mexico specimens diverge slightly from those described by Farran (1913) in two respects. The first segment of the endopod of the first pair of feet has one seta and the second segment of the exopod of the fourth pair of feet has one inner seta. These segments as described and figured by Farran have 0 and 2 setae, respectively.

In discussing this species, Rosendorn (1917) stated that the endopod of the first pair of feet consists of three segments and not two as shown by Farran. My specimens agree with Farran's in this respect. There is also some confusion regarding the number of setae on the third endopodal segment of the fourth pair of feet. Rosendorn apparently misinterpreted Farran's method of presenting the number and position of the setae on the various endopodal segments of the swimming feet. Rosendorn stated that there are four setae on Farran's figure of the third endopodal segment of the fourth feet and not three setae as he (Farran) mentioned in the text. Actually, Farran indicated in his seta formula that there were three inner edge and one outer edge seta on this segment. In addition there is one seta on the terminal part of the segment which Farran shows in his figure but does not mention in the seta formula given in the text. There is thus a total of five setae on the third endopodal segment of the fourth feet which is also the number present on Gulf of Mexico specimens.

O. simplex is another widespread and abundant species. It has been found in estuaries and neritic waters of the entire Florida west coast (Grice, 1960). I have also found it in samples collected throughout the year at stations located fifteen miles off the Florida west coast.

According to Rosendorn (1917), this is the smallest species in the genus. In length the female varies from 0.44 to 0.49 mm and the male from 0.44 to 0.48 mm.

O. simplex has been reported from the Florida west coast and Florida Keys by Grice (1960).

KEY TO THE SPECIES

The following key is modified from one presented by Rosendorn (1917). It is applicable only to those species collected from estuarine

and inshore-neritic waters of the eastern Gulf of Mexico, and even with these species it is desirable, of course, to check one's determination with the original description.

SEX

- Posterior part of body consists of five segments,
 anterior antennae not geniculate female
 Posterior part of body consists of six segments,
 anterior antennae geniculate male

FEMALE

(example of exopod spine formula used in key— 1, 1, 3 = 1 spine on outer margin of first segment, 1 spine on outer margin of second segment and 3 spines on outer margin of the third segment of the exopod)

I. Rostrum present

- A. In dorsal view, forehead extending in a point *O. plumifera*
 B. In dorsal view, forehead wide, not pointed
 a. Exopod segments of first pair of feet
 with 1, 1, 2 spines *O. similis*
 b. Exopod segments of first pair of feet
 with 1, 1, 3 spines *O. brevicornis*

II. Rostrum absent

- A. Exopod segments of fourth pair of feet with
 1, 1, 2 spines *O. nana*
 B. Exopod segments of fourth pair of feet with
 1, 1, 3 spines *O. simplex*

MALE

I. Exopod segments of first pair of feet with 1, 1, 3 spines

- A. Exopod segments of fourth pair of feet with
 1, 1, 2 spines
 a. Second basipod segment of mandible with
 two blunt projections *O. brevicornis*
 b. Second basipod segment of mandible with
 1 strong and 1 fine seta *O. nana*
 B. Exopod segments of fourth pair of feet with
 1, 1, 3 spines *O. simplex*

II. Exopod segments of first pair of feet with 1, 1, 2 spines

- A. Exopod segments of third pair of feet with
 1, 1, 2 spines *O. similis*
 B. Exopod segments of third pair of feet with
 1, 1, 3 spines *O. plumifera*

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THE ECOLOGICAL EFFECTS OF SEWAGE IN BISCAYNE BAY. OXYGEN DEMAND AND ORGANIC CARBON DETERMINATIONS¹

WALTER R. LYNN² AND WON TAK YANG³
The Marine Laboratory, University of Miami

ABSTRACT

An evaluation of manometric techniques in measuring biochemical oxygen demand in bay-bottom sediments indicates limitations of the method. A wet-oxidation method for the determination of organic carbon is proposed and compared with manometric methods. Carbon determinations are shown to have valid relationship which reflects the readily oxidizable portion of the sediment. The proposed method offers a quantitative relative measure of the carbonaceous content of the benthal deposit; is a simple and rapid test having utility comparable to that obtained utilizing the Warburg; and eliminates the complex experimental procedures and equipment associated with the Warburg B.O.D. test.

INTRODUCTION

This report of research completed on N.I.H. Grant [RG-4062 (C4S)], in part, is concerned with a concentrated study of procedural problems related to the Warburg Oxygen Demand determinations and its application in the study of benthal deposits.

In a previous study by McNulty (1957), an attempt was made to relate the B.O.D. of bay bottom sediments with other ecological and zoological phenomena in order to describe and evaluate pollutional conditions in Biscayne Bay. McNulty utilized manometric (Warburg) methods as a secondary measurement which would reflect concurrently the effects of pollution upon the macroinvertebrates and bottom plants which themselves could then be utilized as pollutional indicators. McNulty also made measurements of specific gravity, moisture content, and particle size distribution to be used in the evaluation of the distribution of benthal macro-organisms.

This report is in part the result of a further study of B.O.D. measurements of bay bottom sediments.

Fair, Moore and Thomas (1941) have presented in great detail an analysis of benthal oxygen demands with respect to the natural purification of streams. Their study presented methods of computing the demands which sludge deposits of varying depths and volatile solids concentration would exert upon the surrounding waters. In tidal

¹Contribution No. 290 from The Marine Laboratory, University of Miami.

²Present address: School of Engineering, University of Miami.

³Present address: Fisheries Department, Pusan, Korea.

estuaries, the problem of oxygen depletion of the waters due to sludge banks alone is less frequently serious except under unusual geographical and tidal conditions. Moore, Hela *et al.* (1955) have shown that the dissolved oxygen in Biscayne Bay varies between 50 and 95% of saturation. With a constantly changing water volume rich in dissolved oxygen, the net effects of the sludge deposits upon the surrounding waters in this estuary are minimal in terms of dissolved oxygen depletion. However, the effects of the settled sludge upon the macroinvertebrates and bottom plants is and can be more readily noted. As such, a study of the aerobic B.O.D. of the sediments was undertaken in an attempt to evaluate the degree of pollution of the sediment and thereby relate this with other ecological phenomena affecting the bottom community life rather than to be able to measure the net physical-chemical effects of the sludge upon the surrounding waters.

FIELD SAMPLING

Apparatus. Core Sampler. The coring device has been modified after McNulty (1957). It consists of a standard plastic tube (2" diam.). The outside wall is reinforced with additional layers of plastic tubing. A rubber ball, with a lead sinker at the bottom and attached with a string, is rested on the top of the core during the sampling.

Plunger. A rubber stopper with a diameter slightly less than the core diameter nailed to the end of a dowel approximately 30 cm long.

Calibrated Tube. A 8 cm plastic tube (2" diam.) graduated in 1 cm division.

Separation Plate: The purpose of this plate is to allow transfer of the mud sample from the sampler to the calibrated tube.

Methods. Lower the sampler into the water keeping the ball on the top of the core. When the bottom is reached push down about 10 cm. Rapidly raise the sampler and place the plunger in the bottom of the plastic core as soon as it leaves the water surface. Push the plunger upward and allow the free water at the top of the core to run off. Place the separation plate on the top of the core and set the calibrated tube. Push upward and bring the sample to the top of the calibrated tube (or to the desired depth of the sample). Remove the calibrated tube by sliding along the plate. Place the sample in the sample container and store in ice chest.

PREPARATION OF ALIQUOT SAMPLE

Apparatus. Blender
Magnetic Stirrer

Mesh Sieve (No. 18 U. S. Standard Sieve, Opening 1.000 micron)
200 ml Diameter Large Funnel

5 ml Injection Syringe with Hypodermic Needle

Aliquot Vial. The aliquot vial volume should be exactly determined with the stopper in place (see below). The vials utilized in this work were made from biological specimen vials which were ground down to a desirable volume, 1.5 ml.

Plastic Vial Stopper. A conical plexiglas stopper shaped as standard B.O.D. bottle stopper.

Vial Holder. Made of a short piece of ordinary wire bent to one end to insert the vial and the other end for handle.

Several 250 ml Graduate Cylinders

100 ml Graduate Cylinder

1,000 ml Ehrlenmeyer Flasks

125 ml Small Ehrlenmeyer Flasks for Sample Container

600 ml Beaker

Warburg Reaction Flasks

Procedure. Mix the sample briskly in the sample container and place the sample into the sieve. Spread the sample evenly over the bottom of the sieve and flush with 100 ml of filtered sea water, gradually washing down all screenable materials into the 250 ml graduate. Add the water through the sieve until the level reaches to the 250 ml mark. Record the amount of water added (250 ml minus the total water volume added equals the mud volume). Carefully empty the 250 ml graduate into the blender. Rinse the graduate with an additional 100 ml of filtered sea water and pour rinsings into blender. Blend the total 350 ml volume for two minutes. Pour the blender contents into a 600 ml beaker and place the beaker on the magnetic stirrer. The speed of the magnetic stirrer should be adjusted so that the sand particles will be in suspension. While sample is mixing on the stirrer, dip out an aliquot sample using the wire sampler holder. Vial should enter beaker some uniform distance below liquid surface with mouth facing direction of flow. After dipping, immediately seat the plastic stopper. The exact volume of the sample is determined by displacement. With a tuberculine syringe containing 2.5 ml of sea water, flush the vial contents into flasks. (At least three separate aliquots should be taken for each carbon determination. Additional aliquot samples can be placed in Warburg flasks.)

Sampling. When testing a solid or semi-solid such as muds or sedi-

TABLE 1
EVALUATION OF ALIQUOT SAMPLES

Station A. (Sandy Sample)	Net Weight of Sample (g)	Carbon (mg)	MgC/ml Sample
	2.0415	2.63	6.9
	2.0700	2.31	6.1
	2.0950	2.50	6.6
	2.1005		
	2.1335		
	2.0881	2.48	6.5
Mean	1.23%		4.61%
Avg. Dev.	0.0309%		
Stand. Dev.			
Station B. (Muddy Sample)			
	1.6604	8.63	23.6
	1.6700	8.21	22.4
	1.6706	8.02	21.9
	1.6808		
	1.6821		
	1.6728	8.29	22.6
Mean	0.41%		2.65%
Avg. Dev.	0.00796%		
Stand. Dev.			

ments, the problem of sampling error is a considerable one. Some idea of the magnitude of this error encountered when utilizing the laboratory technique indicated in this paper is shown in Table 1. The major sampling errors occur with samples containing more large solids, particularly particles of sand, as might be anticipated. Variations of less than 5% were considered to be acceptable. The total problem of sampling is complex when consideration is given to the potential sampling errors and the conclusions to be drawn from the results of the samples examined. It would seem folly to become more precise than the 5% variation in the aliquot sample when the core samples might reflect 100% to 200% or greater variation when taken distances 5 feet apart.

Manometric techniques. The manometric method for measurement of oxygen uptake rates has been studied by Caldwell and Langelier (1948) and Ludwig *et al.* (1951), and recently accepted as a valid technique by Standard Methods (1955). This method was employed for two principal reasons, A) the mud sample could be kept in suspension and offer assurance that aerobic conditions were maintained in the flasks and B) the rates of oxygen uptake could be closely studied with measurements made as frequently as may be desired.

The reaction flasks were calibrated by the method suggested by Lazarow (1951). A water bath temperature of $25.2^{\circ} \pm 0.1^{\circ}\text{C}$ was selected in an attempt to duplicate bay bottom conditions. Oxygen uptake rates were computed by the following formula:

$$\text{ppm B.O.D.} = 1.430 \frac{k}{V} h$$

where

k = flask constant (1/mm)

V = sample volume (ml)

h = manometer differential (mm)

Analysis of B.O.D. data. In order to understand the oxygen uptake rates an attempt was made to evaluate analytically the characteristic B.O.D. data for the sediment samples. The aerobic B.O.D. of domestic sewage samples generally follows a characteristic curve which reflects the two phases of the demand exerted—carbonaceous and nitrogenous. The carbonaceous phase has been described as a monomolecular reaction of the form $dL/dt = -kL$ or

$$y = L (1 - 10^{-kt})$$

where

k = reaction velocity coefficient

y = the B.O.D. exerted after time t (ppm)

t = the time in days

L = the ultimate B.O.D. (ppm)

Statistical methods worked out by Theriault (1927) and Thomas (1937) are available for the computation of k and L from the experimental data which is in the above form. Unfortunately, such is not the case with organic estuarine sediments. The characteristic curve of this demand (Fig. 1) indicates a reaction which seems to follow the mono-molecular equation for the first 48 hours. However, beyond this time,

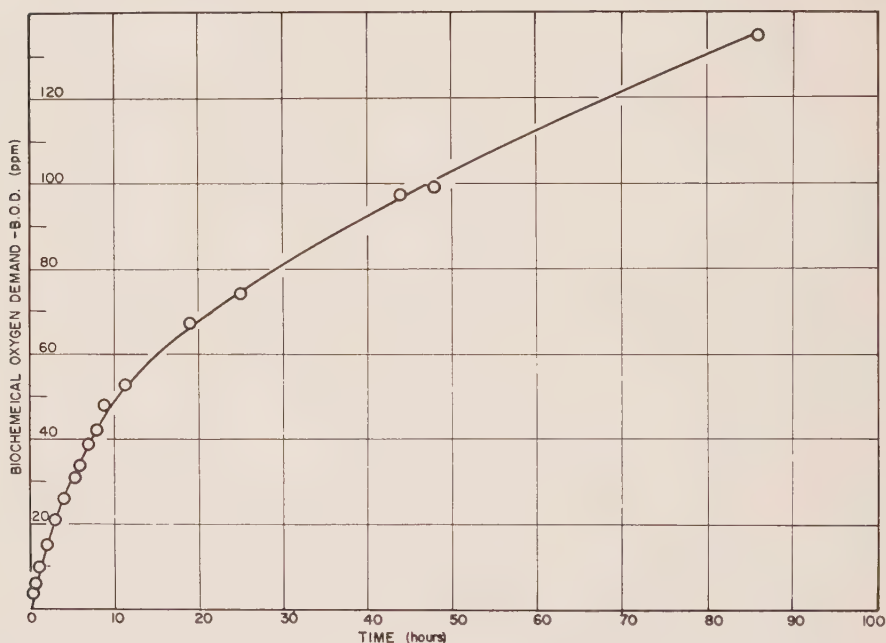


FIGURE 1. Characteristic B.O.D. Curve for Marine Sediments in Biscayne Bay.

the reaction continues at a constant rate for periods exceeding 11 days.

It has been reported that the onset of nitrification is affected by the salinity (Grindby and Wheatland, 1936) and the dilution (Caldwell and Langelier, 1948) of the sample. The evidence seems to indicate that high salinity and low dilutions both exert a retarding effect upon the onset of nitrification. Unfortunately nitrogen determinations were not made of the sediment samples in this study. Caldwell and Lange-

lier reported, in testing primary sewage effluents by standard dilution techniques, that "nitrification begins only after 8 or 10 days and there is little danger of including any of a nitrogenous demand if the incubation period at 20° C is not prolonged beyond 5 days."

Computations of k and L were made for each of the samples studied (Table 2) based on a time period not exceeding 48 hours. The justification for utilizing this time period was based on the fact that this time interval reflected the monomolecular portion of the total reaction and as such, methods for computation of the "Ultimate B.O.D." and the reaction velocity coefficient could readily be made (Thomas, 1937). Studies by Caldwell and Langelier (1948) utilizing the Warburg technique have shown that 85% of the B.O.D. of normal domestic sewage is exerted within 48 hours.

TABLE 2
EVALUATION OF CONSTANTS
FOR
B.O.D. OF BAY BOTTOM SEDIMENTS

Organic Carbon (mg/ml mud)	k^*	L^* (ppm)	B.O.D. at	
			9 hr. (ppm)	48 hrs. (ppm)
24.0	1.65	146	95	172
22.5	1.53	105	71	124
15.5	1.59	96	59	115
14.8	1.22	73	48	99
13.8	2.45	61	43	74
8.3	1.07	43	25	52
6.5	2.55	50	37	63

* k and L values determined by "The Slope Method . . .", Thomas (1937)

Although this is not strictly the case with estuarine muds, a valid analogy was deemed permissible when examining the total reaction.

VELOCITY OF CARBONACEOUS OXIDATION*
BY WARBURG TECHNIQUE

% Ultimate B.O.D.	Time (hrs.)
50	15
66	24
85	48
94	72

*from Caldwell and Langelier

An apparent weakness in formulating the values of k and L from empirical data is that these values are a function of the time period over which the data are collected. Orford and Ingram (1953) have

correctly shown that as the time over which demand data are taken decreases, k values increase and L decreases. Consequently, the values of k and L obtained in this study have little relationship to B.O.D. values for domestic sewage, based on a 5-day time period.

MEASUREMENT OF ORGANICS IN BAY BOTTOM SEDIMENTS

In order to relate the biochemically active sample volume with the rate of oxygen uptake, it was necessary to develop a parameter which would reflect differences in the nutritional composition of the sample. Earlier studies of benthal oxygen demands (Fair *et al.*, 1941) reported oxygen uptake per weight of volatile solids. The volatile solid measurement would thereby reflect the differences in organic composition of the sediment for various samples and volumes analyzed. Initially an attempt was made to utilize volatile solids in this study. It was impracticable to obtain values for volatile solids that would be within an acceptable range of variation. The very nature of marine sediments, which are high in salinity and carbonates in essence negated the use of volatile solids measurement.

Eldridge (1934) has shown that there is considerable variation in the final weights of sewage sludge after ignition. It was found that the temperature of ignition and the time of ignition had a significant effect upon the results obtained. The major difficulty in this study, however, was in determining the dry weight of the sample. The hygroscopic nature of the salts present in the sample and the difficulty in removing the interstitial water seemed to preclude the possibility of complete drying of the sample. Repeated weighings and dryings of the seemingly dry sample produced an endless variety of results (variations of 5 to 30 per cent).

The sample exhibited the same degree of variability with drying times varying from 2 to 48 hours. Attempts to utilize phosphoric acid to reduce the effects of the carbonates was successful, but the breakdown of carbonates was of minor concern. It should be noted that the ignited weights (after two hours in the muffle furnace at a temperature of 600° C) seemed to offer constant results for the fixed solids. However, being unable to obtain a reliable figure for the dry weight made it impossible to compute the volatile solids.

Consequently, it was necessary to find a method which would, (a) offer results that would reflect the amount of organic material present, (b) not require drying as part of the determination and (c) be accurate, rapid and simple.

Investigators of marine and terrestrial soils (Allison, 1935; Corcoran, 1957; Schollenberger, 1927; Wakeel and Riley, 1957; Waksman and Hotchkiss, 1938; Walkley, 1947) have utilized wet oxidation methods which would yield significant results and which would meet the criteria established above.

These methods have been critically reviewed by Walkley (1947). The method basically involves the oxidation of organic carbon with chromic acid and the titrimetric determination of the oxidant consumed. The techniques suggested by previous workers have been further reviewed by the authors and adapted to this particular study.

ORGANIC CARBON DETERMINATION

Reagent. 1 N Potassium Dichromate. Dissolve 49.04 g $K_2Cr_2O_7$ in water and dilute to 1 liter.

50% Phosphoric Acid

Catalyst. 1.25 g Ag_2SO_4 to 1 liter of sulfuric acid.

Sulfuric Acid Conc. Must be at least 96%.

Ferrous-Phenanthroline Indicator. (0.025M.)

0.2 N $Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$. This should be standardized by 0.1 N potassium permanganate before and after each set of titration.

Filtered Sea Water of known salinity.

Method. Add 2 ml of 50% of phosphoric acid into the sample already placed in the 125 ml flasks and mix well. After five minutes, add 10 ml of the potassium dichromate solution and catalyst. Add sulfuric acid in ratio of 2:1. The calculation of the amount of sulfuric acid for dilution and digestion is computed as follows:

$$(A \times B + C + D + E)_2$$

where

A = the volume of one aliquot

$$B = \frac{\text{Total water}}{\text{Total sample plus water (=350 ml)}}$$

C = 2.5 ml of sea water used for flushing

D = 0.1 ml (from H_3PO_4 pf 50%)

E = 10 ml (from $K_2CR_2O_7$ solution)

The sulfuric acid should be added at a constant rate. Usually 10 ml of potassium dichromate solution was sufficient to oxidize the organic matter found in this study. (Additional potassium dichromate may be

required where carbon content is high.) After digestion, cool the sample for two hours. Place the digested sample in a 1-liter flask and dilute with 250 ml of distilled water. Add three drops of the indicator. Titrate with ferrous ammonium sulfate to end point. Color change is from blue green to brown.

Titration of blank. Three blanks of sea water of the same salinity which was used to dilute sample should be run as blanks using the same method as for the sample. The amount of sea water for the blank can be determined by the following equation:

Blank sea water =

$$\text{Volume (of aliquot)} \times \frac{\text{Total volume of water and sample (=350 ml)}}{\text{Total volume of sea water}} + 2.5 \text{ ml (used for flushing)}$$

Computation of organic carbon. The amount of carbon mg in the sample will be calculated by the following formula:

$$\frac{(B - T) \times (A) \times (0.6)}{0.2} = \text{Carbon mg}$$

where

B = ml of ferrous ammonium sulfate solution required for blank titration; T = ml of ferrous ammonium sulfate solution required for sample titration; A = actual normality of ferrous ammonium sulfate solution.

Salinity. Walkley (1947) has correctly shown that the reaction of chromic acid with chlorides forms readily volatile chromyl chloride. The net effect of this reaction is to produce higher values of organic carbon. Rather than attempt to wash the chlorides from the sample as proposed by Wakeel (1957) an attempt was made to determine the net effects of the chlorides in situ and thereby be able to apply a correction for the amount of chromic acid which had reacted with a volume of sea water of known salinity. This correction should then be applied to the value representing the organic carbon.

Walkley also considered the effects of chlorides on the carbon determination. It was suggested that a catalyst (Ag_2SO_4) could be used to "immobilize" the chlorine. The writers found considerable difficulty in dissolving this salt in sulphuric acid as described by Walkley. Corcoran (1957) suggested the use of a similar catalyst

but a smaller quantity thereof. A catalyst (1.25 gms of Ag_2SO_4 /liter of sulphuric acid), was used in determinations of organic carbon in order to minimize the effects of the chlorine.

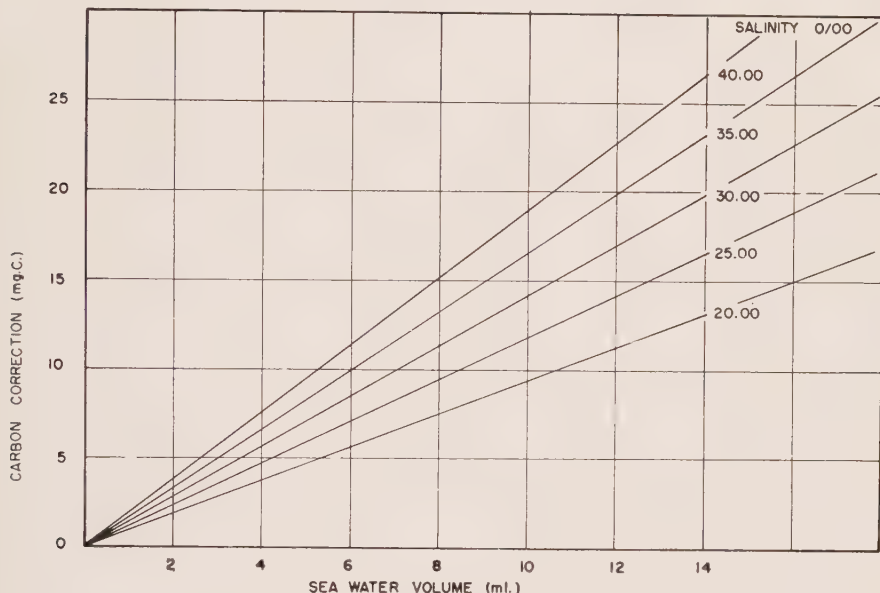


FIGURE 2. Carbon Correction Due to Effects of Salinity.

The determination of a correction is based on empirical evidence utilizing varying quantities and salinities of sea water. The results of these determinations are shown in Figure 2. This graph resolves itself into the following expression:

$$C_c = (0.0472) S V_a$$

where C_c = carbon correction (mg C)
 S = salinity of sample (parts per thousand — ‰)
 V_a = volume of sea water in sample

The correction would be applied to the value for organic carbon determined after titration. The total volume of sea water in the sample is calculated and the correction computed graphically or by the formula shown above. This correction is then subtracted from the value for carbon as determined by titration.

Example: Volume of mud = 80 ml

Volume of sea water added = 270 ml

Aliquot sampler volume = 1.5 ml

Volume of sea water in aliquot = $270/350 \times 1.5 = 1.16$ ml

Wash water (sea water) to flush aliquot sampler = 2.5 ml

Total volume of sea water in flask used for organic carbon determination 3.66 ml

Sea water salinity = 35 ppt then correction:

$$C_c = (0.0472) 35 \times 3.66 = 6.05 \text{ mgC}$$

If organic carbon determination indicated —

carbon content of sample = 17.2 mgC

Corrected carbon content = $17.2 - 6.05 = 11.1$ mg.

A change in the above technique may be employed by utilizing distilled water for washing aliquot sampler. A correction would still need be applied however. The volume of sea water in this case would become 1.16 ml rather than 2.5 ml.

This technique for correction can be avoided while determining the value for the chromic acid blank. However, this requires that the blank be run utilizing the amount of sea water in the aliquot sample (see above example, 3.66 ml or 1.16 if distilled water is used to wash sampler). This has a principal disadvantage of requiring that the volume of sea water in each aliquot be of the same size. This would require running as many blanks as there are different samples. When the number of samples run becomes large, the extra titrations become tedious.

Effect of H_2SO_4 concentration. Walkley (1947) has shown that the rate of oxidation of organic compounds by means of chromic acid approaches a maximum when the ratio of the volume H_2SO_4 to aqueous solution is 2:1 or approximately 75-80% by weight. The writers have substantiated this result and as such have standardized techniques to maintain the volumes of H_2SO_4 : aqueous solution at 2:1.

Variation of the H_2SO_4 to aqueous solution ratio between 1.5:1 to 2.5:1 reflects minor changes in the % recovery of organic carbon.

Effects of carbonates and ferrous minerals. Wakeel *et al.* (1957) have shown that the interference by ferrous minerals is slight (0.06 = 0.01% of carbon) except in blue muds where the iron may be found in a highly soluble form. Carbonate interference is also minimal. To stabilize the carbonates the sample was pretreated with a dilute

(50% phosphoric) acid to remove whatever effects might be exerted by the carbonates.



Ignited bottom sands were examined by the wet oxidation method and were found to exert an insignificant demand upon the chromic acid (— less than 0.01%).

Effect of digestion temperature. For adequate digestion of sample Schollenberger (1927) found it is necessary to boil the sample. Generally higher carbon values were obtained as the time of boiling was increased. It was difficult to obtain constant results due to the variables affecting the time of boiling, principally: a) uneven distribution of heat due to nonuniform flask thickness and dimensions, and b) the unevenness of the heat source.

Standard Methods (1955) suggests refluxing the sample for a maximum time of two hours. The presence of high sulfide and chlorinity creates many problems relative to digestion times. Prolonged boiling causes the breakdown of chromic acid. Water breaks down and acts as an oxidizing agent which reduces the chromate ion, thereby losing its ability to oxidize the carbon compounds.

The method of Walkley which utilizes the heat of reaction for digestion produced uniform temperatures (115-120°C) in the flasks. Although the time of digestion is approximately 5 minutes this method yielded variation of the final results within $\pm 5\%$.

Further, inasmuch as it was attempted to relate the organic carbon content with the B.O.D., the carbon values obtained with the short digestion time exhibited a direct relationship with the more readily oxidizable organic material undergoing oxidation in the B.O.D. test.

Organic carbon testing. Organic carbon determinations were made of many samples in the bay area. Some of these samples were run concurrently with Warburg B.O.D. determination. An attempt was made to take samples from a large portion of the bay area in order to evaluate the results of the test. Figure 3 shows the results of organic carbon analysis of 44 stations in the bay area (Table 3). These points have been interpolated in the figure to attempt to describe the areas of pollution. The isolines accurately describe the polluted bottom areas when examined in light of previous hydrographic, bacteriological and biological analyses (Hela *et al.*, 1957; McNulty, 1957; and Moore, *et al.*, 1955).

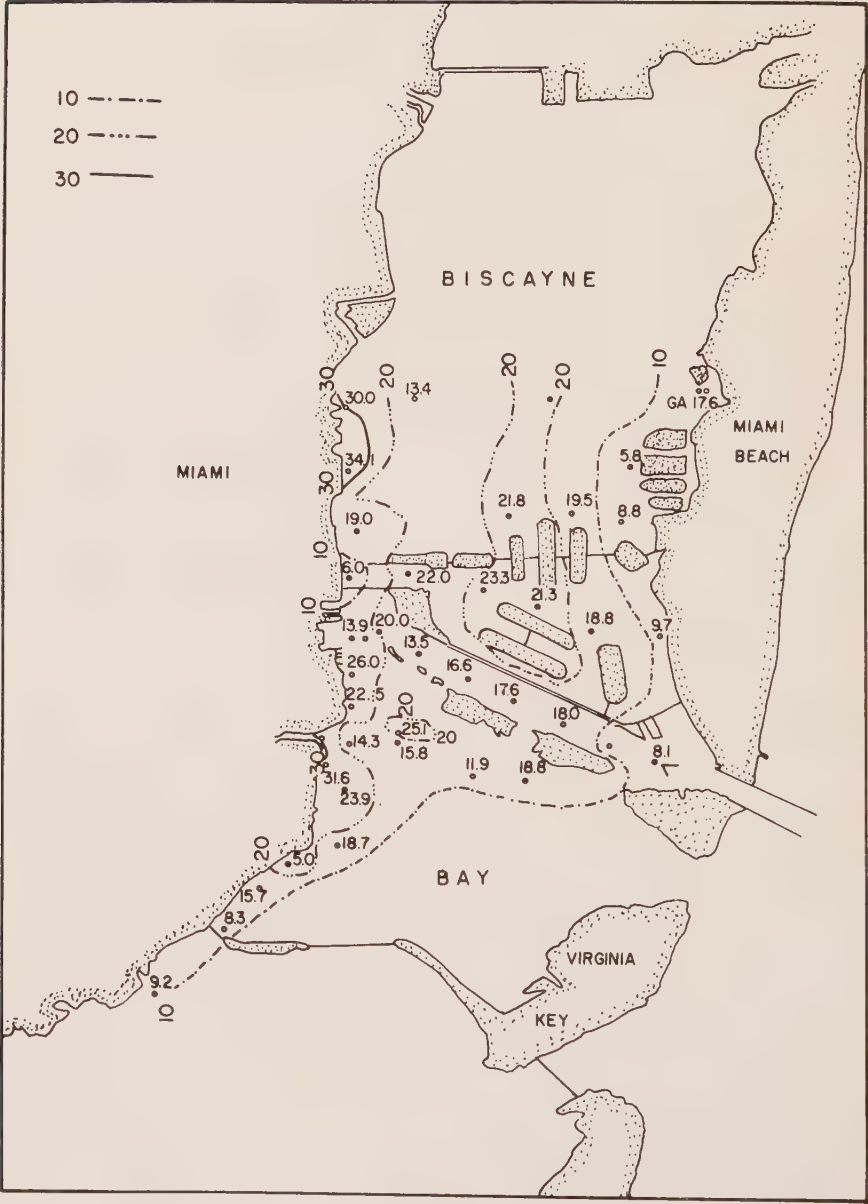


FIGURE 3. Organic Carbon Determinations of Benthal Deposits in Biscayne Bay.

B.O.D. and organic carbon of marine sediments. A comparison of computed L values based upon the 48-hour test period with organic carbon is shown in Figure 4. A linear relationship exists throughout

TABLE 3
ORGANIC CARBON DETERMINATIONS IN BISCAYNE BAY

Station	Carbon (mg/ml mud)
1	9.2
2	8.3
3	15.7
4	18.7
5	23.9
6	31.6
7	23.6
8	14.3
9	22.5
10	26.0
11	13.9
12	6.6
13	19.0
14	21.8
15	19.5
16	8.8
17	5.8
18	6.4
19	21.0
20	13.4
21	30.0
22	34.1
23	22.0
24	23.3
25	21.3
26	18.8
27	9.7
28	8.1
29	18.0
30	17.6
31	16.6
32	13.5
33	20.0
34	18.8
35	11.9
36	25.1
37	15.8

the range of exerted B.O.D.'s as well as with the theoretical ultimate value (Fig. 4). When k values are compared with the organic carbon (Fig. 5) it can be shown (however, less reliably), that as the organic

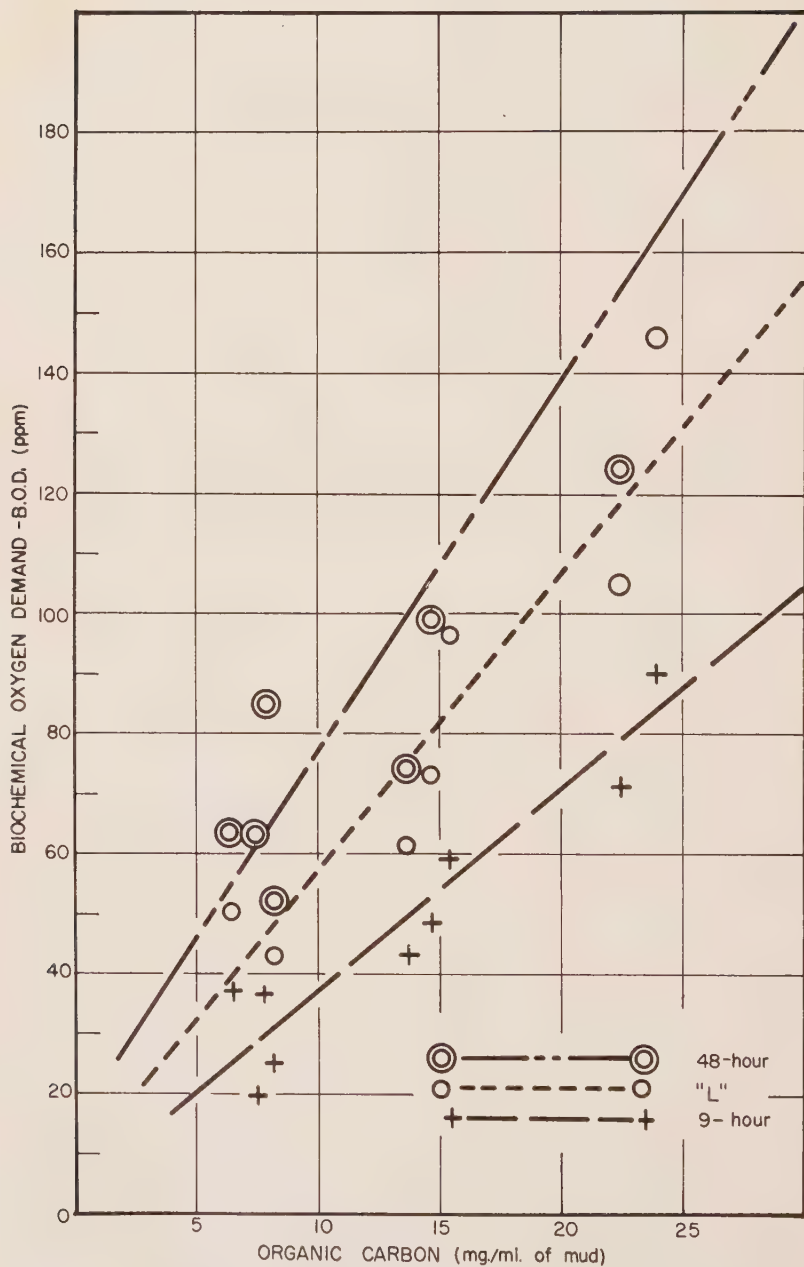


FIGURE 4. Biochemical Oxygen Demand vs. Organic Carbon.

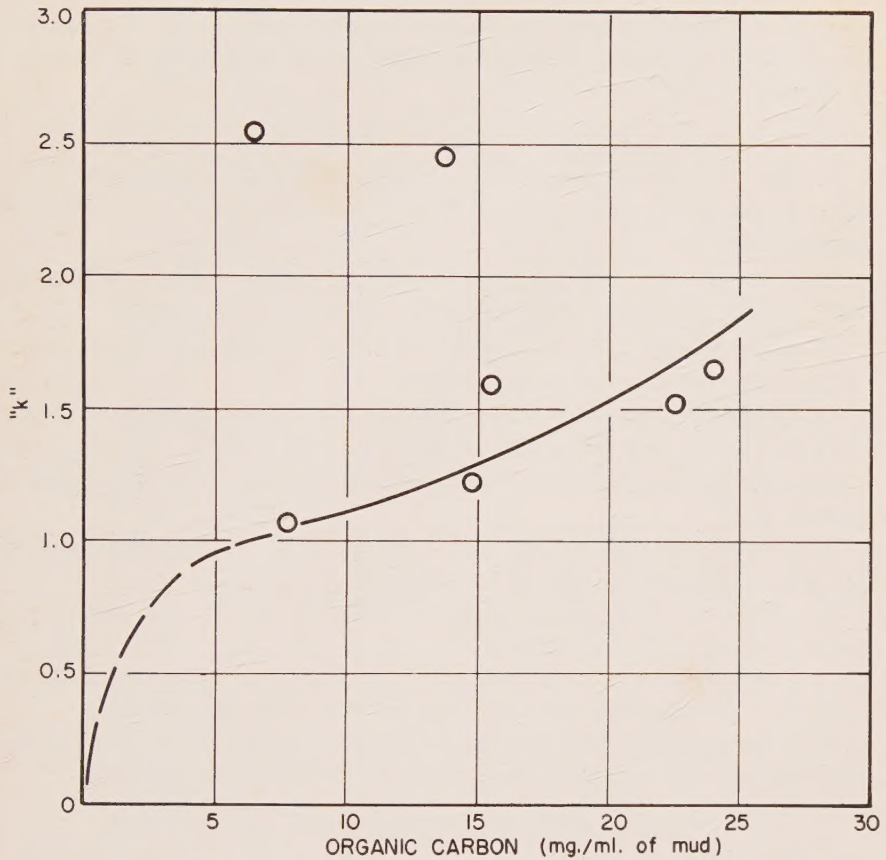


FIGURE 5. Reaction Velocity Coefficient vs. Organic Carbon.

nutrients decrease, the rate of reaction also decreases. The fact that these relationships exist introduces the possibility of substituting the Organic Carbon Test for the B.O.D. as an index of the degree of pollution of estuarine sediments. The organic carbon test is a simple determination which can be completed within a 3 hour period. The Warburg B.O.D. is extremely complex, time consuming, requiring skilled personnel and expensive equipment, and offers results which seem no more valid in terms of describing the degree of pollution of sediment than does the carbon test. Although the organic carbon test is quite similar to the Chemical Oxygen Demand (C.O.D.) a significant difference is presented in terms of the temperature and time of digestion. The shorter digestion period in the organic carbon test

reflects the more readily oxidizable organic portion of the sample which is comparable to that undergoing oxidation in the carbonaceous B.O.D.

SUMMARY AND CONCLUSIONS

1. An attempt has been made to determine the B.O.D. characteristics of estuarine muds. Values of k and L were determined for the samples tested.

2. Concurrently, organic carbon determinations of the sediments were made according to the methods explained in the text.

3. Comparison of B.O.D. data and organic indicates a meaningful relationship between these two indices.

In further studies of estuarine muds, it is recommended that the organic carbon test be utilized rather than the B.O.D. to reflect the pollutional condition of the benthal deposits because the organic carbon test:

a. reflects the most readily oxidizable portion of the sediments and as such is comparable to B.O.D. analysis;

b. offers a quantitative relative measure of the carbonaceous content of the benthal deposit;

c. is a simple and rapid test offering results of comparable value to B.O.D. values obtained utilizing the Warburg respirometer;

d. eliminates burdensome and complex experimental procedures and analysis encountered when utilizing Warburg B.O.D. test.

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